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Effect of Small Doses of Alcohol on a Skill Resembling Driving

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The work described in this Memorandum was undertaken on the recommendation of the Panel on Alcohol and Road Accidents of the Road Users Committee, who also advised on the conduct of the investigation. The Panel had the following membership: E. A. Carmichael, C.B.E., M.B., F.R.C.P. (*Chairman*); D. Russell Davis, M.D., M.R.C.P., D.P.M.; Professor G. C. Drew, M.A.; Miss Grace Eggleton, D.Sc., M.R.C.S., L.R.C.P.; D. C. Haselgrove; Professor A. St. G. Huggett, M.B., Ph.D., D.Sc., F.R.S.; E. I. R. MacGregor; R. J. Smeed, Ph.D.; Professor E. J. Wayne, M.D., Ph.D., F.R.C.P. and R. L. Moore, M.Sc., A.Inst.P. (*Secretary*).

PREFACE

THE work described in this Memorandum was carried out by the authors on behalf of the Committee on Road Users, appointed jointly by the Medical Research Council and the Road Research Board of the Department of Scientific and Industrial Research. A summary of the main findings has already been published in the British Medical Journal*; in addition to the information given there the present Memorandum includes full details of the results and of the experimental method used, together with a survey of earlier work on the physiological effects of alcohol and its effects on behaviour.

The term intoxication, in relation to the drinking of alcohol, is generally used to denote a change in behaviour associated with certain clinical signs such as slurred speech and staggering gait. Some deterioration in efficiency and control, however, almost certainly occurs before these signs appear, and this may well be significant in situations calling for continuous attention and for speed and accuracy of action.

Laboratory studies and also investigations of actual road accidents have suggested that, when the level of alcohol in the blood is relatively high, its measurement may provide a more reliable basis than clinical observation for assessing the impairment of ability to perform a skilled task such as driving a motor vehicle. There is less evidence on the value of blood alcohol measurements at lower levels when clinical signs will usually be absent.

The present study was designed to investigate the effects of small amounts of alcohol which would produce concentrations in the blood below those regarded in a number of countries as evidence of intoxication and within the range of those reached in ordinary social drinking. The 40 men and women studied undertook in the laboratory a series of tests on an experimental task which in a simplified form resembled driving a vehicle on the road.

The main findings regarding the relationship between performance of the task and the observed blood alcohol levels are presented in terms of the average effects on a group of individuals. They show that, in general, performance begins to deteriorate with very low blood alcohol levels and that deterioration progresses as the blood alcohol level rises. There was, however, a wide variation in the effect of alcohol on different individuals, and about a quarter of those tested showed reduced error after alcohol, although most of these did so only by a compensatory reduction of speed. The authors have made some attempt to assess the importance of various personal factors which may account for these individual differences.

Recognition of the existence of individual variation in response to alcohol should not be allowed to obscure the principal result of the study described in this Memorandum. Evidence has been obtained that a high proportion of individuals show a measurable impairment of performance after drinking amounts of alcohol too small to produce even those clinical signs of intoxication apparent to trained observers.

MEDICAL RESEARCH COUNCIL,
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WE are deeply indebted to the Medical Research Council, without whom this work would not have been possible.

It would be difficult to overstress our indebtedness to the Director, and staff, of the Road Research Laboratory of the Department of Scientific and Industrial Research. The Laboratory provided us with accommodation and subjects and supplied much of the apparatus used, including all breath-testing apparatus. We have been closely associated with the Road User Section of the Laboratory throughout and would like to express our gratitude to all its members and especially to Dr. R. J. Smeed and Mr. R. L. Moore for unfailing help and advice.

We should like to express our gratitude to Mr. E. B. Parkes, the Director of the South-Western Forensic Science Laboratory and to Mr. K. Jones of that laboratory for their help in the analyses of body fluids; the analytical procedure was supervised throughout by them. We were provided with accommodation there and helped with equipment. Our analyst was trained by them and the success of this part of the work was largely due to their efforts. The pipettes were designed and, at first, made for us by Mr. Jones.

Our thanks are also due to Mrs. A. Myers who carried out the blood and urine analyses.

The data in Tables 1 and 2 have been taken from *Proceedings of the Second International Conference on Alcohol and Road Traffic*; acknowledgments are due to the Garden City Press Cooperative, Toronto.

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I. Introduction : Metabolism of Alcohol and Some Reported Findings on Behavioural Effects

SINCE the drinking of alcohol in one form or another is so common a characteristic of the social life of man in a variety of cultures, it would seem important that as much as possible should be known both of its physiological effects and of its effects on behaviour. In fact, at the present time, very little precise information is available, in spite of an extensive literature on the subject. This literature has been reviewed, more or less comprehensively, periodically since the early part of this century (Fisk, 1917; Darrow, 1929; Emerson, 1933; Alcohol Investigation Committee of the Medical Research Council, 1938; Jellinek and McFarland, 1940; Drew, 1951).

The most striking feature to emerge from any review of the effects of alcohol on behaviour is the marked lack of agreement between authors, amounting, in many instances, to direct contradiction. This is especially true for the effects of smaller doses. Perhaps not surprisingly, doses large enough to produce clinical signs of intoxication such as slurred speech and staggering gait have generally been reported as resulting in deterioration of efficiency in almost all aspects of behaviour tested. For doses below this level, however, the picture is not clear. Some authors have reported deterioration in performance however small the dose, some have failed to find any effect, while several have reported actual improvements following doses of the order of one single whisky. In part, these discrepancies arise from the complexity of the effects of alcohol, and from the considerable individual differences in response to it. In part, however, they reflect the unreliability of many of the results obtained, due to such factors as inadequate control of dosage, inadequate measurements and control of behaviour changes, and too few subjects. Further, there is insufficient detail in the statement of some results.

Alcohol exerts its effects through the central nervous system, its main pharmacological effect being the depression of central nervous activity, so it is likely that the extent of its effect is closely related to the concentration of alcohol in the brain tissues. It is not possible to measure alcohol concentration in the living brain direct, but there is a constant ratio between this concentration and that of alcohol in the blood. In assessing the effect of alcohol on behaviour it would, therefore, seem desirable to relate the behavioural effects to the concentration of alcohol in the blood, rather than to the amount of alcohol consumed. Indeed, some of the earlier confusion with regard to the effects of alcohol on behaviour has arisen because workers have attempted to relate behaviour changes to the amount of alcohol ingested, without taking into account the effective concentration as reflected in the level of alcohol in the blood. Although it is clear that there is a relationship between the amount consumed and blood alcohol level, this relation is rather a complex one. The concentration which a given dose produces in the blood depends on a number of factors, and it would, therefore, be necessary to know a good deal about the circumstances in which the alcohol had been consumed before the level of alcohol in the blood could be deduced from the size of the dose.

In this section of the report, the metabolism of alcohol, and the relationship between the amount of alcohol ingested and the level of alcohol which appears in the blood, will be first considered and, subsequently, the relationships that have been reported between blood alcohol levels and various behavioural indicators of intoxication.

Factors Affecting the Relation Between the Amount of Alcohol Ingested and Blood Alcohol Concentration

The concentration of alcohol in the blood is usually expressed as the weight of alcohol in a given volume of blood, the units of measurement being grams of alcohol per litre of blood, or appropriate fractions of these. In this report the figures given will represent the number of milligrams of alcohol per 100 millilitres of blood (abbreviated to mg%); quoted figures will be converted to this scale where necessary.

BODY WEIGHT

Since alcohol is absorbed into body tissue in proportion to the water content of the latter, the heavier an individual is, the lower the concentration in the blood will be following the ingestion of a given quantity of alcohol. Strictly speaking the relevant variable is lean body weight, since alcohol is only to a small extent absorbed by fat.

TIME SINCE INGESTION

Alcohol needs no digestion, but is absorbed directly into the blood from the stomach and small intestine by simple diffusion; it is then distributed throughout the body and is subsequently eliminated by oxidation or excretion. However, the rates of absorption and elimination are not usually the same; at any time, therefore, the amount of alcohol available to produce a pharmacological effect, following the ingestion of a given quantity, is the resultant of the absorption rate into the blood stream and the rate of disappearance through oxidation and excretion. Because initially the absorption rate is much faster than the rate of disappearance, the concentration of alcohol in the blood typically rises rapidly to reach a maximum value when most of the alcohol has been absorbed, and falls thereafter more gradually to zero.

The three factors which together produce the rise and fall of blood alcohol following an ingested dose, absorption, distribution, and elimination, will now be considered.

Absorption

The more rapid the absorption rate, the earlier will be the peak, and since the earlier the peak the less time for oxidation, an early peak will tend to be higher than a late peak. The peak usually occurs between 30 and 90 minutes after ingestion, but may be considerably delayed and lowered by slow absorption.

It was suggested by Mellanby (1919) that the absorption of alcohol into the blood stream is completed when the maximum blood alcohol concentration is reached. This is supported by Widmark (1932), Jungmichel (1933), and others. Haggard, Greenberg and Lolli (1941), however, present evidence to show that alcohol absorption from the stomach continues long after the maximum blood alcohol concentration is reached, but that when little alcohol remains in the stomach absorption rate is reduced with the result that it is slower than the rate of disappearance.

The rate of absorption of alcohol is affected by a number of factors.

Absorption will be slowed by the presence of food in the stomach. This increases the time taken to empty the stomach and thus delays the entry of alcohol into the small intestine, from which it is absorbed most rapidly. Goldberg (1951) found that the presence of food in the stomach lowered the blood alcohol curve much more when the alcohol was taken as spirits than when it was taken as beer. For distilled spirits the peak blood alcohol concentration was not reached in some cases until 180 minutes after drinking, and the blood alcohol curve was 30–70 per cent lower when the spirits were taken with food than when they were taken on an empty stomach; but the blood alcohol concentration after drinking beer was not at all or only slightly influenced by the simultaneous taking of food. The nature of the food also influences the absorption rate. Mellanby (1919) found that foods high in fat content were effective in retarding absorption, but that protein had little effect. Later workers have suggested that proteins are also effective in delaying absorption (Tuovinen, 1930; Widmark, 1933; Haggard and Greenberg, 1940; Newman, 1941).

Absorption rate also depends on the amount, the dilution and the nature of the alcohol consumed.

For any individual the greater the quantity of alcohol consumed the faster is it absorbed, though the rate of absorption does not increase in proportion with the increase in the amount consumed (Harger *et al.*, 1937).

The dilution of alcohol affects the rate at which it is absorbed (Mellanby, 1919; Miles, 1924; Goldberg, 1951); this can be seen from the way it affects maximum blood alcohol concentration. Goldberg has shown that the peak blood alcohol level for wines, and for spirits at the dilution of wine, was about 25 per cent lower on the average than that for distilled spirits. The more rapid absorption of distilled spirits results in a high peak and a spiky curve in contrast to the lower peak and rounder curve for wines and diluted spirits; this occurs with spirits because the diffusion of alcohol into body tissues fails to keep up with absorption into the blood (Newman and Abramson, 1942). There is, however, an upper limit to the increase in absorption rate with increase in strength of dose. Newman (1941) pointed out that with highly concentrated doses absorption rate may be lowered because the alcohol may cause inflammation of the tissues of the viscera, followed by an outpouring of protective mucus causing a reduction in the accessibility of the absorbing surface; gastric motility may also be depressed in this way so that emptying time is prolonged. Newman suggests that the maximum speed of absorption occurs when the alcohol consumed is at concentrations of between 10 and 20 per cent. Other investigators have shown that alcohol is more readily absorbed at concentrations of between 10 and 30 per cent (Hanzlik and Collins, 1913; Haggard *et al.*, 1941; Lolli and Rubin, 1943). However, for small amounts of alcohol the factor of dilution is relatively unimportant, as the alcohol is absorbed rapidly irrespective of dilution (Himwich, 1956).

The nature of the drink consumed also has an influence on absorption rate. The greater the buffer capacity of the drink, the slower is its absorption. Newman and Abramson (1942), for example, found that other forms of alcohol buffered to the pH of wine had the same absorption rate as wine. It appears that carbohydrate in alcoholic beverages also lowers the blood alcohol curve; hence whisky, at the same dilution as stout, is absorbed more rapidly (Mellanby, 1919). Goldberg (1951) demonstrated a lower blood alcohol curve for beer than for the same quantity and dilution of alcohol in water. Haggard *et al.* (1941) and Klein (1951) found similar results when comparing beer and sweet wine.

Goodman and Gilman (1956) state that absorption rate is entirely dependent on the emptying time of the stomach, since alcohol in the small intestine is rapidly and completely absorbed whatever its amount, dilution, or nature; these factors, however, exert an important effect indirectly by influencing stomach emptying time.

Newman and Card (1937) state that absorption appears to be inhibited after a time possibly both because there is a slowing of the flow of blood to the viscera, and because alcohol becomes fixed in the mucosa, causing a high alcohol concentration in the intestinal wall and a lower diffusion gradient.

Furthermore, absorption rate varies between individuals. Eggleton (1941 and 1942) has drawn attention to the individual differences and irregularities which exist in the rate at which the stomach is emptied. This could not only produce different rates of absorption in different individuals but also an irregular absorption rate in the individual. Schmidt (1934) gave normal subjects a dose of 0·6 ml per Kg body weight in the form of whisky and soda and observed the maximum blood alcohol level to vary from 40 to 80 mg%, the time of occurrence of this maximum ranging from 15 to 90 minutes after ingestion. He suggests that, as the rates of disappearance were shown to be similar, the differences must have been due to differences in rates of absorption. Newman and Fletcher (1940) found that following the administration of a standard dose of 1 ml per Kg body weight the maximum concentrations for a group of 65 subjects had an approximately normal distribution with a range of approximately 60–130 mg%. Goldberg (1951) quotes data obtained, under fasting conditions, from two subjects of the same body weight who had consumed four bottles of beer; one showed an early blood alcohol maximum of 114 mg%, and the other a later and lower maximum of 61 mg%. It is clearly differences in absorption rate that produce these differences in time and level of peaks.

It has been shown by Miles (1924), Schmidt (1934), Fleming and Stotz (1936), Newman and Card (1937) and Goldberg (1951) that heavy drinkers have a higher rate of absorption of alcohol into the blood and an earlier and higher maximum blood alcohol concentration than light drinkers. It is possible that faster absorption rates are partly due to faster emptying of the stomach in heavy drinkers.

Distribution

After it has been absorbed into the blood, alcohol is rapidly distributed round the body. During the absorption phase, a constant ratio between the concentration in the blood and in the other fluids and tissues tends to be maintained, particularly when absorption is relatively slow. However, the alcohol is distributed at different speeds to the different fluids and tissues, distribution to the cerebrospinal fluid being rather slower than that to most other fluids and tissues. Thus during active absorption, the rising phase of blood alcohol concentration, the level in the cerebrospinal fluid is lower, and during the falling phase it is higher than that in the blood (Lester and Greenberg, 1952).

Alcohol is taken up by the body tissues and fluids roughly in proportion to their water content, and there is, therefore, an unequal distribution of alcohol throughout the tissues. The percentage of alcohol in the brain has been generally found to be about four-fifths of that in the blood (Harger and Hulpieu, 1956). Practical use can be made of the proportional distribution of alcohol throughout the body in making indirect assessments of blood alcohol levels from samples of body fluids (urine and saliva) and expired air. An evaluation of the use of urine and breath analysis for estimating blood alcohol content is given in Appendix A.

Widmark (1932) introduced a formula for finding the amount of alcohol in the body from body weight and blood alcohol concentration. This formula contains the factor 'r' expressing the proportion of alcohol in the blood to that in the tissues. He found that, after the consumption of spirits, 'r' for men varied from 0·60 to 0·76 and for women from 0·50 to 0·60. The value of 'r' was somewhat higher after the consumption of beer, being about 1·0. Other investigators have found similar values of 'r'. For example, Newman and Lehman (1938) found 'r' to be 0·7, and Goldberg (1951) found that 'r' for distilled spirits averaged 0·721 and for beer 0·89. The latter found a slight decrease in 'r' with increase in the amount of alcohol taken. The value of 'r' is approximately constant for a given animal species. Eggleton (1940) points out that the variation between species is presumably due to varying fat content, as the fat contains only 10–20 per cent of the blood plasma concentration.

Elimination

The disappearance of alcohol from the body is the result of metabolism and excretion combined. Most of the alcohol is metabolized; only 1–5 per cent is excreted in the urine, depending on the amount and dilution of alcohol ingested and on the volume of urine produced, and a maximum of 5 per cent lost in faeces, breath and sweat. Alcohol is oxidized to acetaldehyde, then to acetic acid. The second step is much faster than the first, so acetaldehyde concentration is low. Acetic acid is the normal intermediate in the oxidation of fats and carbohydrates, and alcohol can therefore produce calories in the same way; seven large calories are produced per gram of alcohol. Eighty per cent of the alcohol is metabolized in the liver, and the rest in the kidneys and other tissues (Lester and Greenberg, 1952). The rate of metabolism seems to be determined by the amount of functional liver tissue.

Unlike the absorption rate, the rate of disappearance of alcohol is resistant to change. Attempts made to increase the rate through increased urine output or increased respiration have been unsuccessful because only small amounts of alcohol are excreted unmetabolized. It has also been shown that exercise does not increase the rate of alcohol metabolism. Attempts to increase the rate by means of drugs or diet have also been unrewarding. Although Himwich (1956) concludes from a review of previous studies that under certain limited conditions amino acids, or a combination of glucose and insulin, will facilitate alcohol metabolism, the evidence that alcohol metabolism can be increased is generally regarded as inconclusive.

It is established that there is an approximately rectilinear fall-off in the blood alcohol level in the post-absorptive phase; an average rate of disappearance of alcohol from the blood of 15 mg% per hour is generally accepted. The straight-line fall-off was first suggested by Mellanby (1919), and was confirmed by Widmark (1932) who derived the factor β describing the decline in terms of the number of milligrams of alcohol which disappeared from 1 ml of blood in 1 minute. While agreeing that the disappearance of alcohol is rectilinear, Newman, Lehman, and Cutting (1937) suggested that larger doses are metabolized more rapidly, so that the slope of the line is steeper. The work of Goldberg (1951) supports this view.

Goldberg found that 1 pint of beer will take 2 or 3 hours to disappear, and 7 pints will take 9 hours. He also found that an equivalent amount of alcohol in the form of distilled spirits will take longer; for example, 15 whiskies (equivalent to 7 pints of beer) will take 15 hours to disappear. It is clear that even for relatively small doses a considerable time will elapse before alcohol is completely eliminated from the body.

The Relation between Blood Alcohol Level and Behaviour

Until metabolized or excreted, alcohol exercises a pharmacological effect on the central nervous system. Alcohol is a primary and continuous depressant and in this respect it shares the characteristic action of the general anaesthetics. That it appears to act as a nervous stimulant is probably due to the fact that the higher centres of the brain are depressed earlier and to a greater extent than the lower, the earlier depression of the higher inhibitory mechanisms freeing the lower centres of the brain from control.

Much has been reported about the changes in behaviour that follow the ingestion of alcohol. It is now generally agreed that a relationship exists between the concentration of alcohol in the blood and the degree of intoxication as judged by clinical signs. Indeed, this relationship is the basis on which have been established the levels of blood alcohol used in some countries to define intoxication for medico-legal purposes. It is not possible, however, to predict with any precision, for any one individual, the effects on performance that will accompany a given level of blood alcohol. Not only does the effect of alcohol on any one kind of performance vary with individuals and with the time since ingestion, but alcohol has been shown to have different effects on different kinds of performance. Thus the effect of a given level of blood alcohol will vary with individual response, the length of time since ingestion, and the kind of performance studied. These three factors will now be discussed.

INDIVIDUAL REACTIONS TO ALCOHOL

The diversity of tolerance to alcohol is well known, as indeed is the diversity of tolerance to all drugs (Nelson, 1939): even when all possible factors are held constant, a quantity of alcohol which causes some disturbance in one individual may have little or no effect on another.

Goldberg (1951) found that given the same dose of alcohol proportional to body weight habitual drinkers were less affected than occasional drinkers, even though the habitual drinkers tended to have higher maximum blood alcohol levels. Jetter (1938) compared an experimental group of occasional drinkers with a hospital population of habitually heavy drinkers, and found that a larger proportion of the experimental group than of the hospital group were judged to be intoxicated when given the same dose of alcohol, the difference being greater for low doses; at blood alcohol concentrations of 75–125 mg %, 50 per cent of the experimental group and only 18 per cent of the hospital group were judged to be intoxicated.

Apart from this acquired tolerance due to habitual drinking, there is a wide range of reactions to alcohol which must be attributed to differences in the inherent tolerance of individuals. Goldberg (1943) and Newman, Fletcher, and Abramson (1942) found a normal distribution of individual tolerance to alcohol. Newman (1947) obtained a bell-shaped distribution curve of the blood alcohol concentrations at which significant impairment of coordination occurred; these concentrations ranged approximately from 40 to 220 mg %.

Reasons for the individual differences in susceptibility to alcohol have been little investigated, but some attempts have been made to relate these differences to personal factors such as age, sex and personality characteristics. Newman and Fletcher (1940) found no relation between age or sex and loss of efficiency in performance after drinking alcohol. Cattell (1930) found some evidence of age and sex difference, his women subjects being more affected than his men subjects, and his middle-aged subjects showing improvement on each of two tests after alcohol. Wierenga (1936) found the effect of alcohol much greater in a 'choleric' subject than in a 'phlegmatic' one. Bartley and Chute (1947) quote Sheldon as observing that viscerotonic individuals (characterized by 'general relaxation, love of comfort, sociability, conviviality, gluttony for food, for people, and for affection') not only enjoy alcohol but even benefit from small quantities, while cerebrotonics (characterized by 'the element of restraint, of inhibition, and of the desire for concealment') are said to be adversely affected by alcohol even in small doses. Cattell (1930) distinguished a group of his subjects who improved with small doses of alcohol and deteriorated with caffeine from a group who showed the reverse effects. The former he described as '"people who live on their nerves", sensitive, and unstable, very reserved and obstructed in some forms of response and yet free in others, erratic and, as individuals, either dispirited or hypercritical in their general outlook'. By contrast, the group who improved under caffeine he described as 'steady-tempered, possessed of considerable energy, evenly inhibited, moderately introverted, egocentric and self-confident'. It has often been noticed that when depressant drugs are given to psychiatric patients a given dose has a greater effect on patients with hysterical disorders than on those showing anxiety and depressive symptoms. A theory postulating a greater susceptibility of extraverts to depressant drugs was first put forward by McDougall (1929) and has recently been extended by Eysenck (1957a). Experimental confirmation of the greater susceptibility of extraverts to the depressant action of amobarbital sodium has been published by Shagass (1954 and 1957).

THE EFFECT OF LENGTH OF TIME SINCE INGESTION

Since, after a dose of alcohol, the level of alcohol in the blood first rises and then falls to zero, any blood alcohol level which occurs on the rising curve will occur again later when the blood alcohol level is falling. The standard of task performance at a particular blood alcohol concentration on the rising curve has been found to be inferior to that at the same concentration on the falling curve (Mellanby, 1919; Miles, 1924; Schmidt, 1934; Eggleton, 1941; and Goldberg, 1951). Miles suggests that some kind of adaptation occurs. Mirsky, Piker, Rosenbaum and Lederer (1941) also postulated an adaptation of the central nervous system, which permitted symptoms of intoxication to disappear within several hours even when the initially intoxicating blood alcohol level was maintained. However, since a falling blood alcohol concentration always occurs after a rising one, it has not been possible to differentiate the effects of the difference in the direction of movement of the blood alcohol level from the effects of the difference in the length of time the alcohol has been in the body. Eggleton (1941) and Newman *et al.* (1942) claim that the degree of intoxication is dependent not only on whether the blood alcohol curve is rising or falling and on the length of time that has elapsed since ingestion, but also on the rate at which concentration is built up during the absorption period. One of Eggleton's subjects had an impairment of 6 per cent at a blood alcohol concentration of 100 mg% when the rate of increase of blood alcohol concentration was 2·15 mg% per minute, and an impairment of 45 per cent at the same blood alcohol level when the rate of increase was 7·5 mg% per minute.

THE RELATION BETWEEN DIFFERENT KINDS OF PERFORMANCE AND BLOOD ALCOHOL LEVEL

It has been seen that the effect on performance of a given level of alcohol in the blood varies with the individual and with the time that has elapsed since ingestion. The third important variable is the kind of performance that is being studied. It has already been mentioned that the literature presents a confused picture of the effects of alcohol on different kinds of performance, particularly as regards small doses. While this results partly from the complexity of the subject, undoubtedly it is also partly caused by the unsatisfactory experimental techniques often used in this field.

'Clinical' Behaviour

A person is commonly said to be intoxicated, or 'under the influence', when he exhibits such characteristic behaviour as unsteady or erratic gait and confusion of thought and speech, and indeed deterioration of this kind is regarded as clinical evidence of intoxication. Further, it is generally accepted that there is a relation between these clinical signs of intoxication and blood alcohol level, and in some countries this has been used as a basis for legal definitions of intoxication. However, a study of the literature shows that it is not possible to define a precise relation between blood alcohol level and 'clinical' behaviour because clinical judgement of the effect of alcohol has been found to be an unreliable measure; Liljestrand (1940), Goldberg (1951), Loftus (1957), and Penner and Coldwell (1958) all give evidence of considerable variation in diagnosis made by different clinicians.

Clinical judgement is thus an unreliable measure of the effects of alcohol even when clinical signs are present, and it is questionable whether it is an appropriate basis on which to assess the effects of alcohol on the performance of a skilled task such as driving a car. The complex and recently acquired aspects of behaviour are more readily impaired than others (Jellinek and McFarland, 1940) and are therefore likely to be affected at blood alcohol levels below those at which clinical signs of intoxication appear; there is evidence from laboratory and field studies that such performance is affected below these levels.

Sensory Responses

Most studies have been concerned with touch, vision and hearing, but some work has been done on pain sensitivity; measures have been made of the effects of alcohol on the absolute sensitivity of the sense organs (absolute threshold) and on their sensitivity to changes in the stimulus (difference threshold).

The experiments on difference thresholds, though in the main carried out on few subjects, give fairly consistent results which show that even small doses of alcohol increase the threshold, the subjects becoming less sensitive to, and less aware of, change in stimuli. Both Lichtenfels (1851) and Kremer (1884) found a marked decrease in skin sensitivity as judged by capacity to differentiate two skin contacts from one; it was necessary to increase the distance between the contacts by 93 per cent before they could successfully be differentiated 90 minutes after a moderate dose of alcohol in a fairly strong solution. Lange and Specht (1914), Miles (1924) and Busch (quoted by Jellinek and McFarland, 1940) all report decrease in sensitivity to differences in visual stimuli. Visual acuity similarly suffers after quite small doses. Subjects are normally unaware of these changes in visual efficiency. According to Jellinek and McFarland (1940), the auditory difference threshold is similarly changed. Depth perception appears to be impared with moderate doses (Newman and Fletcher, 1940, and Newman, Fletcher and Abramson, 1942).

The absolute sensitivity of sense organs seems to be reduced by large doses, but is either unchanged or is even increased by small ones. Lange and Specht (1914) (quoted by Jellinek and McFarland) found an increase in sensitivity for both vision and hearing after small doses, but Harrisen (Jellinek and McFarland) found a decrease for hearing; Mullin and Luckhardt (1934) report a marked decrease in sensitivity to pain. Bjerver and Goldberg (1950) found an average impairment of 32 per cent on a flicker fusion test and of 35 per cent on a blink test in subjects having an average blood alcohol level of 56 mg%; the threshold of impairment occurred at a blood alcohol concentration of 20–30 mg% on the flicker test, and 40–50 mg% on the blink test. The impairment increased to a maximum and then decreased slightly in advance of the corresponding rise and fall of blood alcohol. The authors claim 'Alcohol had the same effect on vision as the setting of a grey glass in front of the eyes, or driving with sun glasses in twilight . . .'. They attribute this effect to the suppressive effect of alcohol on the inhibitory components of the retina involved in dark adaptation, and suggest that this adds to the evidence that for small doses the fact that alcohol appears to stimulate is probably due not to a stimulation of the central nervous system but to a paralysis of inhibitory centres.

Reaction Time

Effects on reflex responses. Much of the work on the delay in reflex responses following the ingestion of alcohol has been done with apparatus which is now obsolete, and the measurements are unreliable. Most experiments in which modern recording instruments have been used (e.g. Travis and Dorsay, 1929) indicate that the delay in reflex response is shortened, that is, the reflex response is speeded after alcohol. The above authors report a decrease in reaction time for the patellar reflex, varying from 18 per cent after 30–40 ml of alcohol in a concentrated solution to 38 per cent after 100 ml. The maximum effect appears to be reached between 30 and 45 minutes after ingestion. This increased speed of the reflex accords with the view that alcohol is a central depressant, since the increased speed can be accounted for by the release of lower centres from higher control. Dodge and Benedict (1915) also found increased speed of response in the patellar reflex. On the other hand, Miles (1924) reported a decrease in both speed and amplitude in eyelid responses but his recording apparatus was not very satisfactory.

Effects on voluntary responses. Here again, shortcomings in experimental techniques make any exact statement of the effect of a particular dose of alcohol impossible. From the data of many different experiments tabulated by Jellinek and McFarland (1940) it seems clear that the effect of any dose of alcohol is ultimately to increase the reaction time to visual, tactile and auditory stimuli. The amount of increase reported is, however, very variable (Exner (1873), Miles (1924), Niemirowicz (1938), Cavett (1938).)

Of considerable interest are the results of Kraepelin (1883, 1896), Warren (1887), and Niemirowicz (1938) in which shorter reaction times are recorded in the first few minutes after taking alcohol. In general, approximately 3 per cent decrease in time has been recorded, though Niemirowicz reports decreases as large as 24 per cent. Jellinek and McFarland (1940) regard these decreased times as artifacts. They base this conclusion on the fact that reaction time experiments show considerable practice effects, and that it has been the custom with all these authors to compare post-alcohol readings with the average of pre-alcohol readings. While this must throw grave doubt on the results quoted, it would appear premature, in view of the improvement of skills noted by some authors following small doses, to ignore the possibility of a decrease in reaction time in the first few minutes.

From the point of view of driving, the fact that all doses appear to lengthen the reaction time after a short interval would seem to be the important consideration.

More Complex Behaviour

Coordination. While the literature indicates that small doses increase both the strength and speed of simple muscular responses, such as strength of grip, in ergographic tasks, these doses seem to produce impairment in all tasks requiring coordination. Dodge and Benedict (1915), Miles (1924), Bahnsen and Vedel-Petersen (1934) and McFarland and Barach (1936) have all reported impairment of a variety of simple coordination tasks after relatively small doses. Vernon, Sullivan, Greenwood and Dreyer (1919) and Miles (1924) found a marked decrease in accuracy of typing and a slight decrease in speed.

Driving—experimental studies. On more complex tasks, Vernon (1936) using the original 'Miles Trainer', a machine designed to simulate car driving (described on p. 18), found an increase in error and in speed in his drivers following a dose of whisky diluted to give 30 ml of absolute alcohol in 20 per cent solution. He noted that his drivers showed greater variability in speed, tending to drive in short bursts of speed and to suddenly slow down. Newman and Fletcher (1940), using a series of tasks designed to be analogous to driving, found, with a dose giving a mean peak blood alcohol concentration of approximately 100 mg%, an overall relationship between blood alcohol concentration and the degree of impairment in performance. No actual improvement in performance was found, though some subjects felt that they did better with alcohol and others expected that they would improve. In a carefully controlled series of experiments, Bjerver and Goldberg (1950) tested experienced drivers on six tasks designed to measure their skill in manipulating a motor-car. After 40 or 53 ml absolute alcohol taken either as beer or as diluted spirits, and resulting in a blood alcohol level of 40–60 mg%, the time required for each manoeuvre was increased; the increase varied from 3·3 per cent on a 'Blocks' test, where the car had to be steered to knock over 3 blocks placed on a gentle curve, to 71·8 per cent in the time taken to park the car.

Borkenstein (1956) tested 16 male subjects on a series of practical driving tests similar to those used by Bjerver and Goldberg, except that performance was measured in terms of the number of stanchions struck. The number of white lines crossed was also recorded, and scores were allocated for car handling errors by the passenger observer. All subjects were given two trials; some took alcohol on their second trial; the blood alcohol levels obtained ranged from 60–240 mg%. Drivers with blood alcohol levels over 150 mg% had a mean increase of 40 errors over their initial score, drivers with blood alcohol levels of 70–140 mg% had a mean increase of 12·7 errors, while the control, non-drinking, drivers had a mean increase of 3·5 errors.

Coldwell (1957), using the same driving tests as Borkenstein, measured the impairment of 50 drivers after they had drunk alcohol. He found that a majority of drivers with blood alcohol levels below 80 mg% showed evidence of impaired driving ability, and that all subjects with blood alcohol levels between 80 and 150 mg% showed evidence of impairment.

Loomis and West (1958) measured change in reaction time, time off course, and time taken to complete the course, for subjects operating a simulated automobile training device. A direct relationship was found between blood alcohol level and impairment of function. Impaired performance was demonstrated in all 10 subjects at a blood alcohol concentration of 50 mg%, and at 150mg% the performance had decreased to approximately two-thirds of the control values.

Most investigators measuring driving impairment have measured, essentially, ability to co-ordinate; Cohen, Dearnaley and Hansel (1958) are more concerned with judgement. They show that at blood alcohol levels of 60–80 mg% there is a significant increase in the hazards incurred in driving a bus through narrow gaps, and at the same time an increased confidence of success in doing so.

Driving—accident studies. Many of the above authors have pointed out that the tasks performed in these tests present neither emergencies nor other hazardous situations which may occur in normal driving. They also suggest that the test situation may induce higher motivation to perform well; if this were so the effect of alcohol in a real driving situation might well be greater. Two field studies have been carried out, one in the United States and one in Canada, in which the proportion of drinking drivers in groups of individuals involved in traffic accidents was compared with the proportion in non-accident groups.

The first, a study by Holcomb (1938) in Evanston, Illinois, compares the distribution of blood alcohol levels in a group of 270 drivers involved in accidents resulting in personal injury who were examined by Heise from 1935 to 1938, with the distribution in a group of 1,750 non-accident drivers examined in the course of one week. Table 1 shows the percentage of drivers in the two groups at different blood alcohol levels.

TABLE 1

Levels of blood alcohol found in accident and non-accident drivers : Evanston study

(Adapted from Lucas, Kalow, McColl, Griffith and Smith, 1955)

Alcohol in blood (mg%)	Accident drivers		Non-accident drivers		Ratio of per cent accident to non-accident drivers
	No.	Per cent of group	No.	Per cent of group	
No alcohol	144	53·4	1538	87·9	0·6
Trace to 60	39	14·2	133	7·6	1·9
70 to 100	28	10·4	56	3·2	3·3
110 to 140	22	8·2	16	0·94	8·7
150 and above	37	13·8	7	0·45	33·1

TABLE 2

Levels of blood alcohol found in accident and non-accident drivers : Toronto study

(Adapted from Lucas, Kalow, McColl, Griffith and Smith, 1955)

Alcohol in blood (mg %)	Accident drivers		Non-accident drivers		Ratio of per cent accident to non-accident drivers
	No.	Per cent of group	No.	Per cent of group	
0 to 50	328	77·5	1839	91·3	0·85
50 to 100	30	7·1	109	5·4	1·31
100 to 150	17	4·0	39	1·9	2·10
150 and above	48	11.3	28	1·4	8·10

In the second study (see Table 2), carried out in Toronto, Lucas, Kalow, McColl, Griffith and Smith (1955) questioned the comparability of the accident and non-accident groups used by Holcomb; to ensure comparability of their own groups, for each of their accident drivers they obtained data from four or more non-accident drivers who had passed the scene of the accident at the time. 423 accident drivers and 2,015 non-accident drivers were tested.

It is clear from these two studies that the percentage of drivers with a given blood alcohol level was greater in the accident groups than in the non-accident groups when this level was greater than 50 mg%; further, above 50 mg%, as blood alcohol level rose, the percentage with a given blood alcohol level increased very much faster in the accident groups than in the non-accident groups.

Further, Haddon and Bradess (1959) show that in single vehicle accidents—those involving no other vehicle or pedestrian —in which the driver was killed the proportion of drivers with alcohol in the blood was higher than the proportion of drivers with alcohol in the blood in accidents in general. They found that 49 per cent (of 83 drivers) had blood alcohol levels at death of 150 mg% or more, while the levels of an additional 20 per cent fell between 50 and 150 mg%. These figures may be compared with those given in the Toronto and Evanston studies mentioned above. Haddon and Bradess conclude that in single vehicle accidents in which the driver is killed alcohol is likely to be an important causative factor. The Delaware accident statistics for 1957 support these findings; all the fatalities classified as single vehicle fatalities were examined, and it was found that 67 per cent (of 15 drivers) had blood alcohol levels of 150 mg% and two drivers had levels between 100 and 150 mg%.

EVIDENCE FOR A THRESHOLD

The possibility of there being a threshold of impairment has been mentioned by several investigators. Mellanby (1919) observed that an individual may show no symptoms of intoxication at a given blood alcohol level but may be severely intoxicated at a blood alcohol level only slightly higher. Newman and Abramson (1942) found a striking threshold effect for an aiming task when they arranged for the blood alcohol level in their subjects to rise gradually over a period of several hours; the threshold, under this special condition, ranged from 65 to 157 mg%. Bjerver and Goldberg (1950) report that impairment of driving ability begins at 35–40 mg%, but they had very little information about performance below this level on which to establish a threshold. Goldberg (1950) suggests that the threshold varies with the task being investigated. Holcomb (1938) concludes from his field study that accident liability begins to increase when the blood alcohol level rises above 50 mg%.

SUMMARY

It is clear that, in moderate to large doses, alcohol produces a marked deterioration both in sensory capacity and in the ability to perform complex tasks. There is also evidence that blood alcohol levels below those associated with clinical signs of intoxication are accompanied by impairment of complex skills and by increased accident liability. Previous research has not made it clear, however, at how low a dose this effect starts, or even whether low doses produce an improvement and higher doses a deterioration. There seems to be some support from past work for the hypothesis that different individual effects associated with personality variations may be expected from low doses.

II. The Present Investigation

Aims

The experiment reported here had two major aims:

1. To investigate the relationship between the performance of a task resembling driving* and the blood alcohol levels resulting from small doses of alcohol.
2. To consider individual differences in response to alcohol in relation to other personal characteristics.

An additional aim was to evaluate methods of indirect estimation of blood alcohol concentration from urine analysis and from different techniques of breath analysis. The findings from this part of the study are reported in Appendix A.

Experimental Method

In this experiment the performance of 40 subjects on a simulated driving task was tested both under 'normal' conditions (placebo dose) and after the ingestion of 4 different doses of alcohol. Blood, urine and breath samples were taken at intervals during the performance of the task. All subjects were given a number of personality tests before they began their series of driving tests.

A pilot experiment was conducted beforehand with 6 subjects. This was designed to test the sensitivity of the scoring devices and the general suitability of the driving apparatus, to find the appropriate alcohol dose levels to be used, and to gain experience in collecting and analysing samples.

It has been noted that many of the results of previous work of this kind are difficult to interpret because of failure to control various aspects of the total situation. In designing this experiment, therefore, care was taken to keep conditions as constant as possible.

SUBJECTS

The subjects for the experiment were all obtained from the staff of the Road Research Laboratory. The great majority were scientific or experimental officers; the remainder were from the 'industrial' staff. All subjects were volunteers. Obtaining subjects by asking for volunteers has certain disadvantages; for example it is always doubtful whether a true sample of personality variations is obtained by a volunteer method. In the present case it had the further disadvantage of excluding all total abstainers from the experimental population. However, it is neither easy nor desirable from a motivational point of view to use other than the volunteer method for experiments of this kind.

Forty subjects were used in the main experiment. The mean age of the group was 31 years; 39 subjects were between 23 and 40 years of age and there was one considerably older subject of 58 years. Five of the subjects were women. All subjects held current driving licences, though driving experiences varied considerably. All subjects were asked to report their normal drinking habits and it was found that the majority were occasional or moderate drinkers. All were in good health at the time of the experiments. Though no detailed measurements were made, it is probable, from the nature of their employment, that the subjects were not a representative sample of the general population in intelligence, but were, as a group, above the national average; there were certainly no individuals of low intelligence amongst them.

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*Actual driving was undesirable partly because of the extreme difficulty of scoring behaviour at all accurately, as the situation to which the driver is responding cannot be controlled to any extent, and partly because it was undesirable to risk an accident with a driver who had taken alcohol for the purposes of this experiment.

ALCOHOL DOSES

As this research was concerned with the effects of small amounts of alcohol, it was decided to use as the largest dose one which would give a maximum blood alcohol concentration of not more than 100 mg% as this is well below the concentration accepted in the United States as that at which 50 per cent of a population will be intoxicated. Preliminary tests indicated that a dose of 0·65 grams of alcohol per kilogram of body weight could be expected to yield a blood concentration of slightly less than this figure. This was therefore used as the largest dose. It is the approximate equivalent of three pints (48 fl. oz.: 1,700 ml) of 'average' beer, or 5 fl. oz. (142 ml) of whisky, for an 11-stone (70 Kg) man. Three other alcohol doses were used to cover the range between this dose and zero alcohol; these were 0·20, 0·35 and 0·50 grams of alcohol per kilogram of body weight. (The doses given to subjects were based on total body weight, rather than estimated lean body weight, but since the blood alcohol levels resulting from any one dose varied little, it would appear that the effect of this was negligible.) A placebo dose containing no alcohol was used for control purposes.

In view of the report of Haggard, *et al.* (1943) that the effects of different brands of the same type of spirit vary considerably, it seemed desirable to use the 'purest' form of alcohol. Therefore absolute, 'analar' grade, ethyl alcohol was used. The alcohol was given as a 20 per cent solution since this was likely to maximize the blood alcohol levels obtained (see p. 3). In order to provide a placebo dose which was not clearly a placebo to the subjects, all the drinks were heavily flavoured with ginger and peppermint mixed with lime, lemon or orange, in an attempt to disguise the taste of alcohol. This appeared to be successful since subjects showed chance accuracy at the time of drinking in deciding whether or not they had been given alcohol. Some 20–30 minutes after drinking the largest dose they were all aware of having had alcohol, but were very inaccurate in estimating the quantity.

THE TASK

Since blood alcohol concentration changes with time from drinking, first rising and then falling steadily, it was necessary to obtain measures of performance change over a reasonably long period; it was also necessary to give the subjects a continuous task which would keep them occupied for most of the period; the period chosen was two hours. Short performance tests were unlikely to prove of much value, since, as has already been stated, a considerable amount of evidence exists to show that under these conditions compensatory responses may give an entirely unrealistic picture of general performance level.

While compensatory responses are less likely to confuse the general picture in long duration tasks, these tasks have their own special difficulties. Performance scoring usually becomes complex and laborious. More important, subjects are very liable to become bored, especially if they are required to perform the task on several occasions, and boredom is as likely to introduce complications as are compensatory reactions. It was desirable, therefore, that the task to be used in this experiment should be of some intrinsic interest so that subjects could be expected to work for some time without boredom. It was finally decided that 'driving' on the apparatus known as the 'Miles Motor Driving Trainer' provided the best compromise between a task at which performance could be scored adequately, and one which had the motivating capacity of a real-life situation.

From the subject's point of view the task was one of 'driving' a car along a rather winding country road; it proved interesting, and the subjects were willing to participate for the length of time required by the experimental design. The task was repetitive in that the subject drove round the same track many times in the course of a single trial, but its repetitive nature was not obvious to him. The subject was aware that he was driving round a continuous track but usually went round many times before realizing that he had negotiated a particular section before. The repetitive nature of the task had great advantages for scoring, as it meant that the objective task presented to the subjects was the same at all stages of the experiment.

It is not claimed that the task is any more than a complex tracking task; it clearly differs in many ways from driving a real car on a real road. For example, because of the limitations imposed by the scoring system it was not possible to provide intersections, nor could obstructions or 'other traffic' be made to appear on the track. However, the basic skills required appear to be similar to those of driving, and it seems that considerable positive transfer of skill exists between driving a car and controlling this apparatus: drivers rated as good car drivers proved to be efficient on this apparatus, those having poorer ratings were less efficient, and non-drivers could not control it without a considerable learning period.

For purposes of scoring performance, it would ideally have been desirable to instruct each subject to drive in a standard 'correct' manner. However, this procedure would have destroyed whatever apparent validity the task had, since for example in real driving, if one subject drives slightly nearer the left-hand kerb than another it is a matter of opinion whether or not his driving is better than the other's. In order to make the general conditions correspond as far as possible to those of actual driving on a road, the subject was asked to drive as he normally would, and his performance without alcohol was used as the standard against which to measure his performance after each of the four alcohol doses.

MEASURES OF PERFORMANCE

The performance of the subjects at the task was measured in terms of elapsed time (giving a measure of speed), tracking error, kerb-bumpings, steering-wheel movement, accelerator movement, brake movement, and gear changes. (Further details are given on p. 29).

APPARATUS

The general layout of the apparatus is shown in Fig. 1. The subject sits in a darkened room in the Miles Motor Driving Trainer, a dummy car fitted with normal car controls and indicators, facing a translucent screen (Plate 1). Behind the screen there is a horizontal perspex disk mounted on a vertical axis (Plate II). Outlined on the disk is a continuous winding road, which has a number of reasonably sharp corners; the road edges are marked by raised plastic strips.

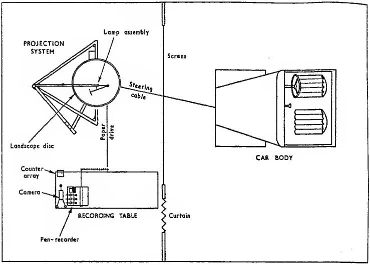

FIG. 1. The apparatus.

The equivalent length of the track is slightly more than one mile. The rest of the disk is painted green, for contrast, and model trees are scattered over it (Plate III). A small fixed lamp, placed immediately above the disk, and on a level with the driver's eye, casts on to the screen a much magnified silhouette of that part of the disk (and the road) lying between the lamp and the screen. From his position, the driver has the impression of sitting in a car on a road surface.

The disk is moved on the horizontal plane by an electric motor, through a friction gear-box, and as it moves the subject in the car has the impression of progressing along the road. The speed of the disk's movement is controlled by accelerator, brake and gears, and the car is steered along the 'road' by the operating of the steering wheel, which rotates the disk in the direction required.

With this equipment, then, it is possible to simulate driving along a road reasonably closely. The method used loses something in realism when compared with film projection techniques, but its advantage for this kind of experiment is that it allows far greater flexibility of response; if the driver makes a sufficiently big mistake in this apparatus he can 'leave the road' altogether. The apparatus has disadvantages in that the optical system does not permit very clear delineation of the edges of the road, the lamp is always visible as a glow 'ahead' of the car, and shadows of supporting struts are cast periodically on the screen; the general impression is one of driving in twilight into a rather dim setting sun. Subjects very rapidly became used to these conditions, however, and did not appear to be worried by them once they had had a preliminary practice period.

The apparatus was modified so that performance of the subjects could be recorded. The movements of the 'car' were indicated by recording the path taken by the projection lamp relative to the edge of the track. A sprung feeler arm was mounted on the lamp carriage, with an extension resting against the left-hand edge of the track (Plate IV). A nylon cord, anchored to the feeler arm, passed through a pulley system to the recording table where it was attached to the carriage of a moving pen. Excursions of the lamp laterally on the track moved the feeler arm nearer to or further from the lamp carriage; the recording pen followed these movements and drew a track on moving paper representing the resulting changes in distance of the car from the left-hand kerb. The paper was driven by shafting from the car drive so that its speed of movement was proportional to the speed of the car.

A second moving pen recorded the angular extent of all movements of the steering wheel large enough to produce any change in the course followed by the car, that is to say, all movements of the steering wheel other than those which were made in taking up back-lash in the control mechanism.

A third moving pen recorded all changes in the position of the accelerator pedal. A fly-wheel mounted on the apparatus gave some degree of 'run-on' after the pedal had been lifted, but apart from this, speed changes followed movements of the accelerator pedal pretty closely, so that the position of this pen gave a reasonably accurate indication of the speed at which the subject was driving.

A further six pen recorders of the simple 'on–off' type were used to indicate on the moving paper the occurrence of various events. One pen recorded the occasions when the car bumped the side of the road, a second and third recorded gear changes and brake applications; a fourth indicated the completion of each lap of the track and incidentally triggered a camera, which photographed counters; a fifth pen recorded the passing of certain salient points on the track, such as the beginning and end of corners, so that it was possible to identify accurately the part of the track over which the subject was 'driving', the sixth pen recorded seconds of time, from which a more accurate estimate of speed could be obtained where necessary.

A continuous graphical record of many aspects of the subjects' behaviour was thus obtained. To ease the labour involved in scoring such records, rotary counters were installed at appropriate points in the recording system linkages in order that scores (in arbitrary units) could rapidly be obtained of the excursions of the moving pens which were recording movement of the car, steering wheel, and accelerator pedal. Electro-magnetic relay counters were used to count time in seconds, changes in the direction of rotation of the steering wheel, and applications of the brake. All these counters were photographed once each lap, using a Siemens 15 mm. single-shot electrically activated instrument camera.

These recording devices together gave a reasonably complete picture of accuracy and speed of 'driving', together with information about the way subjects manipulated the various controls. Subjects were aware that their performance was being scored, but did not know any details. The entire recording apparatus was hidden behind the screen.

MEASUREMENT OF ALCOHOL CONCENTRATION IN THE BODY

The main measures of alcohol concentration in the body were the concentration in the blood and in the urine. In order that the curves of alcohol concentration in blood and urine could be accurately estimated over each experimental driving session, it was desirable to take samples of both fairly frequently during the sessions. At the same time, however, it was undesirable to make excessive demands on the subjects and to break into the driving task too often. It was therefore decided to take the samples at half-hourly intervals during each two-hour session, during a break in the driving session of sufficient length for this purpose. Breath samples were also taken from some of the subjects during these breaks in driving, always within five minutes of the blood and urine samples.

Blood, urine, and—where appropriate—breath samples were taken as usual after the placebo dose, to prevent identification of this dose by the subjects, to provide blank samples as controls for the analytic techniques, and to detect the presence of Ketone bodies, salicylic acid, and sugar.

Blood samples were taken by the pin-prick method. Although the subjects did not like the procedure only one potential subject refused to take part in the experiments for this reason.

Since only small quantities of blood can be obtained by the pin-prick method, a microanalytic technique had to be used in estimating blood alcohol. This was the modified Cavett method recommended by Kent-Jones and Taylor (1954). Although a microscopic technique could obviously have been used with the urine samples, it was thought preferable to use the same technique as was used for blood to ensure the comparability of the findings. Adjustments had to be made to a small number of the 1230 blood and urine alcohol values obtained; six had to be discarded as obviously wrong; in eight cases the values for adjoining half-hour samples had to be reversed, since the shape of the curve indicated that a mistake had been made in sample identification. Missing values, 50 in number, were estimated from the individual curves, or were allotted the appropriate group mean value. Where serum had to be analysed, due to clotting of blood samples, the result was reduced by one sixth. Negative values were taken as zero. Details of the breath analysis techniques employed are given in Appendix A.

MEASUREMENT OF PERSONALITY

A series of personality tests were carried out on each subject with a view to discovering whether individual responses to alcohol are related to personality characteristics. These tests were administered individually on the day when the subject came for the half-hour practice period that preceded the first experimental session. Tests measuring different dimensions of personality were included in the battery, since it was not clear which aspects were likely to be the significant ones—though the literature suggested that introversion–extraversion, and the neurotic dimension were relevant. Some of these tests were of the questionnaire, 'inventory', type and some were performance tests. The tests used were:—

(*a*) Minnesota Multiple Personality Inventory, giving measures of schizophrenia, psychasthenia, depression, psychopathic deviation, hysteria and hypomania.
(*b*) Bernreuter Personality Inventory, Neuroticism Scale.
(*c*) Rosenzweig Picture Frustration Scale, giving a rating of conformity to group standards and the direction of aggressive responses.
(*d*) Maudsley Personality Inventory, giving measures of extraversion and neuroticism.
(*e*) Porteus Mazes (1950), scored for speed/accuracy ratio to give a measure of extraversion (Foulds, 1951).
(*f*) Triple Tester, giving a measure of level of aspiration (Himmelweit, 1945).
(*g*) Hand Steadiness, used as a measure of neuroticism.
(*h*) Size Constancy, used as an index of introversion-extraversion (Thouless, 1932).
(*i*) Body Sway test (Hull, 1933), used as an index of neuroticism (Eysenck, 1952).
(*j*) Reversible Figures, time for first reversal and rate of subsequent reversals, used as indexes of manic and schizoid tendencies (McDougall, 1926, and Guilford and Braly, 1931).

The conditions of administration and scoring suggested by the various authors of these tests were rigidly adhered to.

EXPERIMENTAL DESIGN

In view of the known wide individual differences in response to alcohol it was necessary for each subject to be given all the alcohol doses in order to assess the effects on the group of the different doses. Moreover, it had been decided that each subject should serve as his own control without alcohol, i.e. that his performance after alcohol should be measured against his individual performance under no-alcohol conditions. This meant that each subject was tested on five separate occasions, after each of the four alcohol doses and after the placebo dose.

Repetitive testing has special problems arising from the complicating effects of learning on the one hand, and boredom on the other. It has been seen that boredom was controlled as far as possible by making the task interesting. The pilot study had suggested that considerable practice effects were to be expected on the five driving trials, so that allowance had to be made in the main experiment for this. The fact that subjects were likely to improve with practice meant that the order in which the doses were given was important; the use of an ascending order of dosage would mean that any deterioration due to increased alcohol might be obscured by improvement due to practice, and the use of a descending order of dosage, acting in the same direction as practice effects, might lead to an exaggerated picture of improvement due to decreased alcohol. It was therefore necessary to give the doses to the subjects in different orders. However, it was also necessary to restrict the number of orders used so that in each case the number of subjects given the same order was sufficient to allow some assessment of individual differences to be made.

These apparently conflicting requirements were met by a design in which the same 5 × 5 latin square was replicated eight times, using fresh subjects for each replication. With the restriction that each treatment appeared once only in each column and row, the five doses were distributed randomly throughout the square. The square is shown in Table 3; the code is:—

Dose 0 .. placebo control, no alcohol.
Dose 1 .. 0·20 grams alcohol per kilogram body weight.
Dose 2 .. 0·35 grams alcohol per kilogram body weight.
Dose 3 .. 0·50 grams alcohol per kilogram body weight.
Dose 4 .. 0·65 grams alcohol per kilogram body weight.

TABLE 3

Design of latin square

Subject	Day				
	1	2	3	4	5
			Dose		
1	3	4	0	2	1
2	4	3	1	0	2
3	1	0	2	4	3
4	0	2	3	1	4
5	2	1	4	3	0

It will be noted that this square does not completely avoid repeated sequences; for example, dose 4 is immediately followed by dose 3 on three occasions. Where repeated sequences appear they have been examined carefully for possible interaction effects; so far as can be seen these are negligible.

When the first five subjects had had all five doses a new group of five subjects was given the same dose orders, then another, until the eight replications of the latin square had been completed. The fact that five different orders of dosage were used meant that the possibility of the mean alcohol effect being distorted by practice effects was minimized in each replication of the latin square; the repetition of each of these five orders on eight occasions meant that five groups of subjects were obtained within each of which individual comparisons could be made. Subjects 1, 6, 11, 16, 21, 26, 31 and 36, for example, all received the doses in the same order, and so their individual responses to alcohol could be compared.

In order that sex differences might be evaluated, one of the replications of the latin square contained all the five women subjects. The male subjects were assigned to the remaining replications at random.

PROCEDURE

Each subject was tested on one morning a week for five consecutive weeks. During the week preceding the first of his experimental trials each subject was allowed to practice for 30 minutes on the apparatus, to enable him to become familiar with it. No alcohol was given, but blood samples were taken to accustom him to the technique in order to avoid possible complications arising from apprehension of the procedure during the first experimental trial.

Only one test series was held on each day throughout the experiment. The dose was always given at the same time, at 10 a.m.; this time was chosen to ensure that the blood alcohol level would have fallen to an insignificant level by 5.30 p.m. when the subjects had to travel to their homes.

To keep all factors as constant as possible, each subject was tested not only at the same time of day, but on the same day of the week for each of his five trials. Thus subject 1, for example, was tested from 10 a.m. to 12.30 p.m. each Monday for five weeks, subject 2 was tested on Tuesdays, and so on. This schedule was adhered to throughout the experiment with a few minor alterations necessitated by illness, etc.

The condition of the stomach when alcohol was administered was kept as constant as possible. Subjects were asked to take breakfast approximately 2 to 2½ hours before testing began and to keep it as fat-free as possible. They were also asked not to drink alcohol on the previous evening and to report if they felt unwell or had had disturbed sleep. It was necessary to postpone only two tests for such reasons.

The daily experimental procedure was as follows. The subject, having previously been weighed, was first asked to give a urine sample.* This was used mainly to check that no alcohol remained from the previous night, though it also provided a check for the presence of ketones, etc., as already mentioned (p. 20). He was then given his drink containing the alcohol dose appropriate to the trial, and allowed 10 minutes in which to finish it. He was encouraged to drink steadily, but most subjects disliked the taste of the drinks and tended to drink slowly. At the end of a further 10 minutes the subject entered the apparatus and was instructed to 'drive' as he normally would if driving a real car on a road. He was further instructed not to stop, unless an emergency arose, until told to do so. The experimenter then withdrew and the subject, alone in the room, began to drive. After 20 minutes (i.e., 30 minutes after finishing the drink) he was directed to stop and to leave the apparatus. After his hand had been warmed, cleaned and sterilised, a blood sample was taken. A urine sample was then obtained, and, where appropriate, a breath sample also. All samples were obtained within a 10-minute period, at the end of which the subject re-entered the apparatus and continued to drive for a further 20 minutes. The sampling procedure was then repeated. Samples were thus taken at 30, 60, 90 and 120 minutes after drinking. In a few cases further samples were taken during a period of four hours after driving stopped, i.e., up to six hours after drinking. After the subject had left, the blood and urine samples were packed and despatched for analysis; except on rare occasions, they were analysed within 24 hours of despatch.

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* It will be noted that the alcohol doses were taken after the bladder had just been emptied. To investigate the effect of this on concentration of alcohol in the urine a subsidiary series of experiments was conducted after the main experiments were completed, using some of the same subjects; in these subsidiary experiments the alcohol doses were taken when the bladder had not just been emptied. The ratio of blood alcohol to urine alcohol was not found to be very different (see Appendix A).

Results

The alcohol concentrations in blood and urine obtained after ingestion of the four doses of alcohol will be presented first, and then the performance levels accompanying the blood alcohol concentrations will be given. The performance changes will be discussed first in terms of group effects; individual differences will then be outlined; and finally, the relationship between these individual differences in response to alcohol and other personal characteristics will be examined.

ALCOHOL CONCENTRATION

Blood Analysis

The blood alcohol concentrations for each subject at four half-hourly intervals after the ingestion of each dose are given in Appendix C (Table C 1).

As already mentioned, the four alcohol doses were chosen to provide reasonably equal steps in peak blood alcohol concentration between the zero concentration of the control and a maximum of less than 100 mg% for the largest dose (see p. 16). The mean and standard deviation of the actual concentrations obtained from each dose are given in Table 4. Individual differences in absorption rate and the limits of accuracy of analysis combine to make the standard deviations large compared with the means for the low concentrations.

TABLE 4

Mean blood alcohol levels and standard deviations at four different times after drinking, for four doses

Dose	Blood alcohol (mg %)							
	Time after drinking (min)							
	30		60		90		120	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1 (0·20 g./Kg.) .	23	10	19	9	13	8	6	5
2 (0·35 g./Kg.) .	36	15	37	10	30	9	20	9
3 (0·50 g./Kg.) .	58	14	59	11	51	12	39	10
4 (0·65 g./Kg.) .	74	19	77	12	71	14	62	15

While the means for these low concentrations are therefore only suggestive, those for the larger concentrations are relatively reliable. It will be observed that the highest blood alcohol levels obtained for the four doses were roughly 20, 40, 60 and 80 mg%; the doses used have therefore been effective in producing concentrations normally regarded as low or 'safe'. The size of the standard deviations implies that the technique of adjusting the absolute quantity of alcohol given to a subject to his total body weight produces reasonably consistent blood alcohol values among the subjects.

Table 5 gives the mean peak values for blood alcohol in this experiment and those predicted from Widmark (1932) and Goldberg (1951). These mean values (and the mean times of peaking) for both blood and urine alcohol levels were obtained by averaging the peak values and peaking times obtained from the 'best fit' curves of the individual subjects.

TABLE 5

Comparison of the peak blood alcohol levels in the present experiment with some predicted from the results of previous investigations

Source	Peak blood alcohol level (mg%)			
	Dose 1	Dose 2	Dose 3	Dose 4
Present experiment	26·3	43·1	64·4	85·8
Predicted from Widmark . .	31·8	55·6	79·5	103·7
Predicted from Goldberg . .	36·2	53·6	71·0	88·4

It can be seen from Table 5 that the peak values in this experiment are below those expected from both Widmark's (1932) and Goldberg's (1951) calculations, though the differences between them and Goldberg's figures are small. As Goldberg's concentrations were higher than those of the present experiment a difference might be expected; Goldberg has shown that the concentration in which alcohol is administered tends to affect the peak value, higher concentrations tending to produce higher maxima on typically spiky shaped curves whereas lower concentrations have lower maxima on more rounded curves.

The rise and fall of mean blood alcohol concentration for each of the four experimental doses is shown in Fig. 2. The points plotted represent the mean concentrations for the group at the four 30-minute intervals after drinking. For each dose, the concentration of alcohol in the blood rises steeply to reach a maximum between 30 and 60 minutes after drinking. The fall-off is fairly linear once the peak has been passed. To see whether this linearity persisted measurements were taken up to six hours after drinking for some of the subjects. It can be seen from Fig. 2 that the concentration following the smallest dose had fallen to near zero by two hours; the additional measurements showed that dose 2 reached this point at about four hours, dose 3 at rather over five hours, and that at six hours dose 4 still gave a mean concentration of 20 mg%. Once the peak had been passed blood alcohol levels fell, on the average, by approximately 16 mg% per hour.

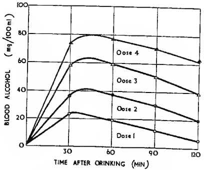

FIG. 2. Mean blood alcohol at four different times after drinking, for four doses.

The curves in Fig. 2 suggest that the peak occurs later with increase in size of dose. That this later peaking is a real phenomenon is shown in Table 6, which gives the mean time of peaking for each dose together with the standard deviation. The maximum concentration resulting from the largest dose occurs nine minutes later than that from the smallest dose.

TABLE 6

Mean peaking times of blood alcohol for the four doses

Dose	Peaking time (min after drinking)	S.D.
1	33·0	10·85
2	39·0	13·09
3	41·0	12·26
4	42·0	11·85

The average time taken to reach the maximum concentration ranged from 23 to 63 minutes in different individuals, and subjects tended to be consistent over the four doses in peaking either early or late with respect to the median. When the observed and expected frequencies of early and late peaking were compared, this tendency was found to be significant (by chi-square $P<\cdot 001$).

The faster the alcohol is absorbed into the blood stream, the earlier the maximum blood alcohol level is reached for a given dose; and since an earlier peak allows less time for the alcohol to disappear through metabolism it will be expected that the earlier the peak is, the higher it will be. These data show a trend in this direction, early peaks being, on the average, slightly higher than the later ones, but the relation here is not statistically significant. Two of the subjects had markedly late and low peaks.

The women subjects (No. 16–20) tended to have peaks consistently higher than those for the men; this was probably because women have a greater amount of fatty tissue which does not absorb alcohol.

The blood alcohol curves given in Fig. 2 are based on the mean concentrations at the four times of sampling, and in effect they mark the terminal points of the changing concentrations affecting the subjects during each 20-minute driving period. The performance figures to be given later are, however, the means for these periods. Therefore, to obtain a slightly closer approximation to the effective concentrations during driving, the mean blood alcohol level at the mid point of each driving period was estimated. The values are graphed in Fig. 3.

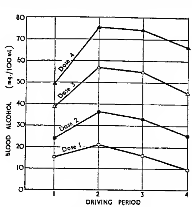

FIG. 3. Mean blood alcohol in successive driving periods, for four doses.

Urine Analysis

The rise and fall of urine alcohol concentrations following the various doses are shown in Fig. 4. The individual urine alcohol values of the subjects are given in Appendix C (Table C2).

The general shapes of the curves are similar to those for blood alcohol, and the rate of fall-off was again linear. Samples taken up to six hours after drinking confirm this. By that time the concentrations resulting from the two smaller doses had been reduced to zero, but a measurable quantity, from 10–30 mg%, remained from the two larger ones.

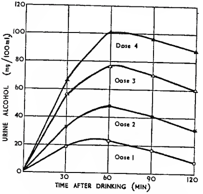

FIG. 4. Mean urine alcohol at four different times after drinking, for four doses.

The urine alcohol peaks, however, were found to be higher than those for blood alcohol; they were also later. Table 7 gives the mean peaking times, calculated as described on p. 25, for the four doses; the peak concentrations were reached 20–25 minutes later than those in the blood.

TABLE 7

Mean peaking times of urine alcohol for the four doses

Dose	Peaking time (min after drinking)	S.D.
1	53·88	14·87
2	60·5	14·0
3	62·13	14·2
4	67·25	12·85

As in blood alcohol, there is a tendency for peaks to occur later after larger doses. Individual differences in average peaking time ranged from 39–88 minutes after drinking. The same two subjects again had later and lower peaks, and the women subjects again showed higher values than did the men.

The relationship between alcohol concentration in blood and urine is discussed in Appendix A, where estimates of blood alcohol concentration obtained from different methods of breath analysis are also evaluated.

PERFORMANCE

For each performance measure a mean score per lap was computed for each five-minute driving period. These five-minute scores were then summed for each twenty-minute driving period.

The performance measures were:

(*a*) Elapsed time (seconds), giving a measure of speed.

(*b*) Extent of tracking error (arbitrary distance units). The score represents the sum of the heights of the curves traced by the car whenever it was travelling transversely to the kerbs. (A zero score would represent no lateral deviation from a course parallel with the kerbs.)

(*c*) Kerb-bumpings (number): collisions with the left-hand boundary of the road.

(*d*) Extent of steering-wheel movement (arbitrary distance units). The score represents the sum of the angular distances through which the wheel was rotated.

(*e*) Reversals of direction of the steering-wheel (number). The score represents the number of reversals in the direction of rotation of the steering-wheel. This was subdivided into:

  (1) Effective reversals: those followed by rotations large enough to produce a change in the course followed by the car.

  (2) Ineffective reversals: those followed by rotations not large enough to change the course of the car.

(*f*) Extent of accelerator pedal movement (arbitrary distance units). The score represents the sum of the distance through which the pedal was moved on each acceleration or deceleration.

(*g*) Application of the brake (number).

(*h*) Gear changes (number).

The scores for speed, tracking error, extent of steering wheel movement, total reversals of the steering-wheel, extent of accelerator pedal movement, and application of the brake were derived from the counter readings, which were photographed once each lap, and the scores for the other measures from the graphical recordings. Certain additional measures of steering accuracy were also obtained by detailed analysis of the graphical record.

Individual scores for (*a*), (*b*) and (*e*) are given in Appendix C (Tables C3–C7). Since not all the data were suitable for parametric methods of analysis, it was decided to use a non-parametric method to test the significance of the alcohol effect on each performance variable.

Each of the eight latin squares constitutes in effect a complete experiment by itself, so that an estimate of significance can readily be made by first ranking for each latin square the totals of the performance scores at the five dose levels and then applying Friedman's two-way analysis of variance of ranked data (Siegel 1956) to these values. This method was employed except in cases where results were only sampled; here 'Student's t' test was used.

In addition to the ranking analysis, analysis of variance was made of the actual scores for those performance measures where the assumptions underlying the use of the technique could be met. Summary tables of the main points of this analysis are given in Appendix B (Tables B1–B6). In these tables the significance of the effects of factors other than the alcohol doses (practice, as measured by trial order, and individual subject differences) can also be seen. Taking the 5 per cent level of confidence as the criterion of significance, there were no cases in which the two methods gave contradictory results. The greater sensitivity of the analysis of variance method, however, tends to give higher levels of significance to the 'dose' effects than those obtained by the ranking procedure.

Practice Effects

A difficulty with much previous work on alcohol has been that practice effects have not been considered. The latin square design used here was intended to balance out such practice effects. An estimate of the effect of practice on any performance measure is obtained by comparing the mean scores for each

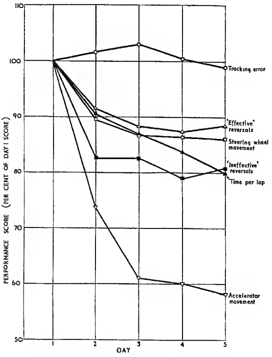

FIG. 5. The effect of practice on six measures of performance.

successive day. For six of the measures the percentage differences from the scores of the first day are shown in Fig. 5 from which it will be seen that the effect varies considerably for different measures.

In general, increasing the speed of driving tends to increase tracking error (the correlation between error and speed is $+0.39$ $P<\cdot 001$). However it will be seen from Fig. 5 that although subjects drive faster on successive trials, there is not a corresponding increase in tracking error. This suggests that there is actually an improvement in tracking performance with practice which is counterbalanced by a speed increase. When the error scores are adjusted for speed some practice effect appears, though it is not a large one.

The breaks in the driving session for blood sampling had a considerable effect on performance, producing a temporary reversal of the trend shown during each period. These effects are shown in Fig. 6 for time per lap and in Fig. 7 for tracking error. It will be seen that while the general tendency is for speed to increase (reduced time per lap) during each period, it is reduced immediately following each break. The trend for error is in the same direction. During each period error increases and each break is followed by a partial recovery. The increase in error during each period, which is present even without alcohol, tends to become more pronounced with increasing size of the alcohol dose.

Accelerator pedal movement shows a very large practice effect. This is in part due to subjects learning that it is in fact unnecessary to change to a lower gear even on the sharper corners.

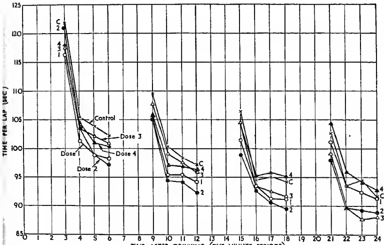

FIG. 6. Mean time per lap (driving speed) at different times after drinking, for four doses of alcohol and control dose.

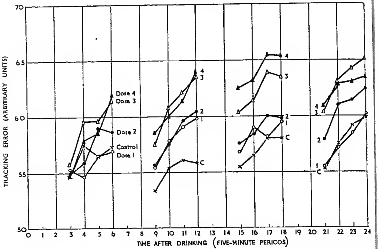

FIG. 7. Mean tracking error at different times after drinking, for four doses of alcohol and control dose.

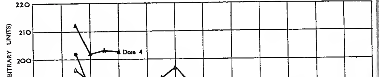

FIG. 8. Mean extent of steering-wheel movement at different times after drinking, for four doses of alcohol and control dose.

A practice effect in the steering-wheel movement score appears as a reduction in the amount of movement both throughout the five trials and during any one trial. This effect, separated out for the different alcohol doses, is shown in Fig. 8. The breaks in a driving session do not affect the tendency towards reduction of movement.

The number of reversals of the steering-wheel also shows a pronounced practice effect in the direction of a reduction in number of reversals both throughout the trials and during any one trial.

Alcohol Effects

Alcohol effects will be considered in relation both to the ingested dose and to the blood alcohol concentration. It is clear that there is a general relationship between these two measures of alcohol such that the greater the quantity of alcohol ingested the greater will be the resultant blood alcohol concentration, though the closeness of the relationship is dependent on the factors discussed in the Introduction. In the present experiments these factors were kept constant, so the relationship between dose ingested and mean blood alcohol level is very close. This relationship can be seen from Fig. 9 which shows the mean peak blood alcohol level for each ingested dose.

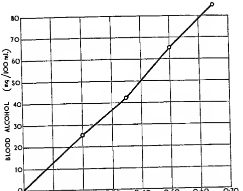

FIG. 9. The relation between mean peak blood alcohol and ingested alcohol.

In setting out the effect of alcohol on the performance measures, accuracy of performance will be considered first, then speed of performance, and finally, operation of the driving controls. In each case the relation between performance and ingested dose will be considered; and in the case of the main performance measures the change in performance with the rise and fall of blood alcohol level will be considered.

Changes in Accuracy of Performance

Tracking error. The mean tracking error for the control dose and the four doses of alcohol is shown in Fig. 10. The alcohol effect is significant at better than the 5 per cent level of confidence (Friedman's test).

Adjustment for the regression of error on speed makes very little difference to the shape of the curve. Dose 3 produced much the same error as dose 4; it also produced some high individual blood alcohol levels which resulted in a

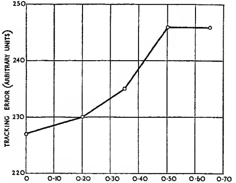

FIG. 10. The relation between mean tracking error and ingested alcohol. (Each point is the mean of four driving period mean scores.)

TABLE 8

Mean tracking error in successive driving periods after drinking, for five doses

Driving period	Tracking error (arbitrary units)				
	Dose 0 (Control)	Dose 1	Dose 2	Dose 3	Dose 4
1	226	223	229	236	233
2	221	232	232	244	244
3	228	234	236	250	257
4	232	231	244	253	249
Session mean	227	230	235	246	246

TABLE 9

Mean tracking error, adjusted for regression of error on speed, in successive driving periods after drinking, for five doses

Driving period	Tracking error (arbitrary units)				
	Dose 0 (Control)	Dose 1	Dose 2	Dose 3	Dose 4
1	236	228	236	244	240
2	224	231	230	246	245
3	227	230	230	247	255
4	229	227	237	245	246
Session mean	229	228	233	246	247

particularly high mean error score for this dose. The alcohol performance curve therefore tends to be straightened when the dose scale is replaced by a blood alcohol level scale (see Fig. 15).

It has been noted that, after drinking, the blood alcohol concentration rises steeply to a maximum, and then returns slowly to zero. Changes in tracking

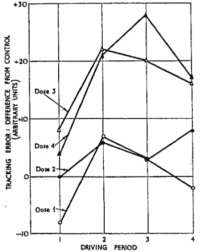

FIG. 11. Mean tracking error (difference from control) in successive driving periods, for four doses of alcohol.

error after drinking show a similar pattern with time, and this is even more marked when speed changes are allowed for.

The mean tracking error scores for each dose in each of the four 20-minute driving periods are given in Table 8. Table 9 gives the same scores adjusted for changes in driving speed. By expressing the dose error figures in Table 9 as differences from the control error figures, the picture given in Fig. 11 is obtained. In this figure control performance should be envisaged as a horizontal line.

It will be observed that Doses 1, 2 and 3 produce a deterioration in performance which reaches a maximum in period 2, that is, between 30 and 60 minutes after drinking. Thereafter performance begins to improve towards the no-alcohol level. Dose 4 produces a deterioration which continues into period 3 before improvement begins. During period 3 for this dose, the average increase in error for all subjects, over their no-alcohol performance, is just under 30 points, that is about 12 per cent. At the end of two hours the error scores were still some 8 per cent higher than with no-alcohol.

It is necessary to consider the relation between change in error and change in alcohol concentration with time. Inspection of the data suggested that the maximum error was reached between the peaking times of blood and urine alcohol and, therefore, that blood alcohol concentration reflects a subsequent performance level and urine alcohol concentration reflects a preceding performance level. This supposition was checked by using a lag correlation technique*. This method expresses the degree of relationship between two variables which are separate in time. It has been shown above, for example, that the concentration of alcohol in urine reflects not so much the concentration in the blood at the same time, but rather the concentration which was in the blood at an earlier time, in this case approximately 20 minutes earlier. Error changes were, therefore, correlated both with blood and with urine alcohol concentrations, with the alcohol concentrations being moved along a time base relative to the error score and re-correlated at each point. Five-minute intervals were chosen and a table of correlation coefficients resulted. These are plotted in Fig. 12.

Though there are differences between doses, in general the highest correlations between blood alcohol and error change occur when the blood alcohol value is correlated with the error score some ten minutes later. Conversely, the best urine alcohol/error correlations obtain when the urine alcohol value is correlated with the error score some ten minutes earlier. Thus, blood alcohol changes would seem to anticipate the behaviour changes which will take place some ten minutes or so later, while urine alcohol reflects what behaviour was some ten minutes or so earlier.

However, notwithstanding the time lag, the similar way in which all these measure rise and fall with time, shown in Fig. 13, suggests that mean blood and urine concentrations are good indicators of mean performance. In this figure the average error for each driving period for the largest dose is shown together with the blood and urine alcohol values for the mid-point of each period. (The urine values have been reduced by one-fifth to make them comparable with the blood alcohol concentrations, in view of the calculated blood-urine ratio of 1:1·252, discussed in Appendix A.)

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* We are indebted to Dr. A. R. Jonckheere of the Department of Psychology, University College, London, for suggesting this technique.

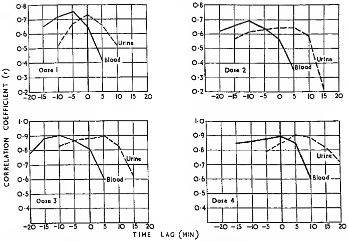

Fig. 12. Lag correlation coefficients between mean tracking error (differences from control scores) and mean blood alcohol, and between mean tracking error and mean urine alcohol, for four doses.

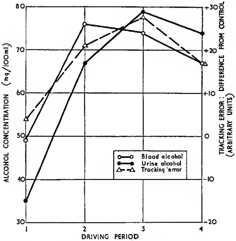

Fig. 13. The rise and fall of mean blood alcohol, mean urine alcohol, and mean tracking error (difference from control) for Dose 4. (Urine alcohol values have been reduced by one-fifth.)

The possibility that blood alcohol level is a good indicator of performance is of interest in view of the reports of previous investigators that the effect of a given blood alcohol concentration is different at different times after ingestion. Because the test ends before the blood alcohol has dropped very markedly, it is not possible from these scores to say with any certainty whether error scores recover more quickly than blood alcohol level drops. It is possible, however, to observe the relationship between blood alcohol level and performance separately for each of the four driving periods, and thus to compare the effect on performance of any given blood alcohol level at different times from ingestion. These relationships are illustrated in Fig. 14. In this figure, for all doses, tracking error (expressed as the difference between control and alcohol performance adjusted for speed) is plotted against blood alcohol for each period. Over the four first driving periods the increase in tracking error with increase in blood alcohol is less marked than is the case with the later periods. Nevertheless, the regression slope of mean tracking error on mean blood alcohol level for the first period is not significantly less than that for any of the other periods, so the overall relationship has been expressed by one slope fitted to all the means, as shown in Fig. 15 (the slope has been adjusted to pass through 0/0). It will be seen from this figure that mean accuracy of tracking decreases progressively as blood alcohol level increases, even at these low concentrations. It appears that, if there is a 'threshold' concentration below which performance is unaffected, it will be below the level obtained from the lowest dose used in this experiment.

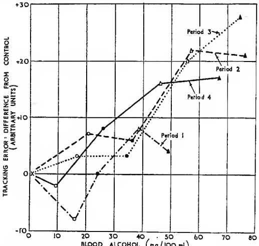

FIG. 14. The relation between mean tracking error (difference from control) and mean blood alcohol in successive driving periods. (Dose symbols as in Fig. 11.)

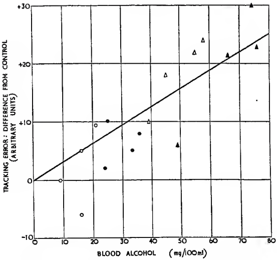

FIG. 15. The regression of mean tracking error (difference from control) on mean blood alcohol. (Dose symbols as in Fig. 11.)

'Kerb-Bumpings'. The method used for scoring tracking error took account only of the amount of deviation and not of its direction, but deviations to the left of the track were more serious than deviations to the right since relatively small swings to the left could result in collisions with the raised edge of the road or, in some cases, in the 'car' running off the road altogether. Subjects were actively discouraged from making this error, as a collision at speed was liable to put the projection system out of adjustment, but in spite of this, and in spite of the fact that a loud buzzer sounded if the 'kerb' was brushed, some subjects did suffer such collisions. It was possible to record these collisions, and so to use them as another measure of error; the total number for each dose and driving period is given in Table 10, and in Fig. 16 the numbers are given as differences from no-alcohol performance.

It will be seen that there is a tendency towards a higher number of collisions with increase in size of alcohol dose (Friedman: $P < \cdot 01$ and for the frequency (difference from control performance) to rise and fall with time approximately in step with the rise and fall of blood alcohol.

Subsidiary measures of accuracy. The tracking error measure discussed so far in this report is a fairly crude one, as it simply totals the extent of lateral deviation of the 'car' across the road surface. Nevertheless, a relation has been shown to exist between the extent of such deviation and the level of blood alcohol, and the two have been shown to vary in time in a similar way. It is possible from this to say that subjects become less efficient with alcohol but not to say precisely in

TABLE 10

Total numbers of 'kerb-bumpings' for 40 subjects in successive driving periods after drinking, for five doses

Driving period	Kerb-bumpings (No.)				
	Dose 0 (Control)	Dose 1	Dose 2	Dose 3	Dose 4
1	68	64	97	59	86
2	32	68	79	75	112
3	51	58	87	58	93
4	58	65	87	68	68
Session total	209	255	350	260	359

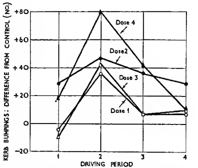

FIG. 16. Kerb bumpings (difference from control) in successive driving periods, for four doses of alcohol.

what ways they do so. To obtain some indication of the latter, two other measures of tracking have been examined. These relate to 'usual' positioning of the car relative to the left-hand side of the road (examined on a sample of 10 subjects using doses 0, 2 and 4 only) and the 'consistency' of positioning at a particular corner (for all subjects and doses). The consistency measure was based on that used by Lewis (1951), who showed that it was a sensitive measure of driving ability. He found that although highly skilled drivers (i.e., police drivers) differed from one another in the way in which they manipulated a particular corner, the performance of each individual was remarkably consistent throughout a series of trials; each man, that is, had a characteristic 'style', almost as individual as hand-writing, which showed itself on each occasion. Less skilled drivers showed much greater variability. The purpose of the present analysis was to determine whether there was any change in the consistency with which a particular corner was tackled after the ingestion of alcohol.

(*a*) *Car positioning*. The width of the road was divided into five equal sections. No. 1 was a strip bordering the left-hand kerb, No. 3 was the crown of the road, and No. 5 the extreme right-hand side. Three measures of car positioning were used, the frequency of entry from any strip to another (indicating the amount of lateral movement), the proportional distance travelled in each strip, and the average distance travelled in each strip per entry. Each of the measures was calculated for the entire 2-hour driving session and averaged on a lap basis.

There is an increase with increasing doses of alcohol in the mean frequency of entry into the various strips. The increase over the control score is significant for dose 4 (Student's t: $P < \cdot 05$). This increase would be expected from the increase in tracking error discussed earlier.

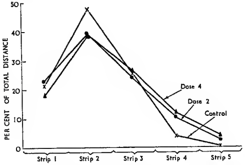

FIG. 17. The percentage distance travelled in each of the five road strips, for two doses of alcohol and control dose.

The distance travelled in each strip per lap is expressed as a percentage of the total lap distance. The percentages are shown in Fig. 17. It will be observed that under control, no-alcohol, conditions subjects drive to the left of, or on, the crown almost all the time. Less than 6 per cent of the total distance is spent on the right of the crown. The distribution, therefore, is highly skewed. Both alcohol doses produce a shift towards the right-hand side, with a less skewed distribution. The mean shift is significant (Student's t: $P < \cdot 05$) for both doses; the effect of dose 4 is not significantly greater than that of dose 2. The effect of alcohol here seems to be a general tendency for subjects to move over towards the right-hand side of the road, but this effect is not increased in proportion to the increase in dosage.

The 2-hour means for the distances travelled in each strip per entry are presented in Fig. 18. Under no-alcohol conditions, subjects tend to remain for fairly long distances on the left-hand side of the road. If they swing over to the right, they correct very rapidly back to the left again. As can be seen from this figure, the distance they travel per entry on the right-hand strip (strip 5) is less than one-tenth of the distance they travel on the extreme left-hand strip (strip 1). After alcohol, however, swings to the right tend to go uncorrected for longer periods, and the subjects tend to swing away from the left-hand side rather sooner. Both of these tendencies are statistically significant for dose 4 (Student's t; $P < \cdot 02$).

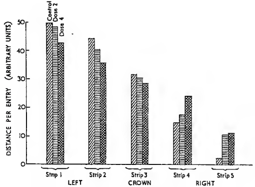

FIG. 18. Mean distance travelled in each of the five road strips per entry, for two doses of alcohol and control dose.

To summarize:—After the control dose subjects tend to drive on the left-hand side of the road, to remain on that side for relatively long periods, and rapidly to correct swings to the right by moving back to the left-hand side. The effect of alcohol is to produce an increase in lateral movement and a shift of the mean position away from the left-hand side towards the crown of the road; with the higher blood alcohol concentration there is an increasing tendency to tolerate swings to the right, and to avoid approaching the nearside kerb too closely.

(*b*) *Consistency.* After a preliminary exploration with a sample of records, it was decided to analyse the behaviour of all subjects in tackling a rather difficult double bend in the track. Seven equally spaced sampling points were chosen before and on the bend, and the distance of the car from the left-hand kerb was observed at each of these points for the first six successive laps in driving period 2, under each dose condition. Thirty-five subjects were used, the graphical records of the other five being insufficiently clear for this purpose. (A similar analysis was made of steering wheel movement. The results of this are described in more detail later).

The ranges of the distance from the left-hand kerb at the seven different points were examined, and as it was found that these ranges showed similar changes with alcohol, they were averaged to obtain a mean consistency score for each dose. These means are given in Table 11, from which it will be seen that in general the score rises as the dose increases. A higher score means less consistency. The alcohol effect is significant (Friedman: $P < \cdot 001$). The effect of alcohol, that is to say, is to make subjects significantly less consistent in their positioning of the car when negotiating the same corner on successive occasions.

TABLE 11

Mean consistency score (car-positioning), for five doses

Dose 0 (Control)	Distance from kerb (arbitrary units)			
	Dose 1	Dose 2	Dose 3	Dose 4
4·8	5·08	5·63	5·78	5·53

Changes in Speed

Speed was measured by time in seconds per lap, and will be expressed in this form. As the task was a self-paced one, allowing a considerable range of speeds, it was expected that there would be considerable variability, not only between subjects, but also within any one session. This turned out to be the case.

The effect of alcohol on mean speed is not significant (Friedman: $P > \cdot 05$). The trend in mean time per lap is plotted against alcohol dose in Fig. 19.

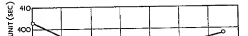

FIG. 19. Mean driving time for four doses of alcohol. (Each point is the mean of four driving period mean scores.)

Although the alcohol effect is not significant the variance of the scores is greater for the larger doses of alcohol. Such an effect could be produced by random fluctuations in subjects' speed from dose to dose, the more marked changes occurring with the larger doses, or it could be the result of some subjects speeding up consistently with increasing doses of alcohol and some slowing down. It was shown (by a standard analysis of variance test between regressions) that some individuals consistently speed up with increase in alcohol dose, and some consistently slow down. These individual differences will be discussed later.

Oscillation in speed within any one lap is shown by the accelerator pedal movements, since the speed of the machine followed accelerator pedal movements very closely. These scores show an extremely skewed, almost J-shaped, distribution. The alcohol effect is not significant (Friedman: $P > \cdot 05$). It has been pointed out earlier that the accelerator movement scores show a very marked practice effect: it may be that such practice effects are swamping possible alcohol effects.

Increasing doses of alcohol therefore have no clear effect on the speed of the group as a whole, but this is to some extent accounted for by the fact that some subjects speed up consistently and others slow down.

Changes in Movements of the Controls

Apart from accelerator-pedal movements which have already been discussed, the only measures of control movement which were analysed in detail were those of steering-wheel operation. Brake and gear movements proved unsuitable for analysis as subjects learned very rapidly that it was not necessary to use the brake, and that the gear lever need only be used when starting from rest. Only a few subjects continued to use the gear-box once they had the machine in motion. Too few scores are therefore available for these two controls to warrant further analysis. It was noted, however, that a few subjects, when bringing the car up through the gears to working speed from rest, found the task of correctly positioning the gear lever more difficult following ingestion of the larger doses. As a result, smooth getaways tended to become less certain. Occasionally, a

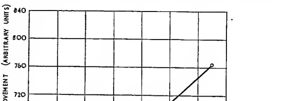

FIG. 20. Mean extent of steering-wheel movement for four doses of alcohol. (Each point is the mean of four driving period mean scores).

subject failed to notice that he had engaged the wrong gear, and attempted to reach his desired speed by excessive acceleration in a lower gear.

Two measures of steering-wheel movement were used; total extent of movement, and number of reversals of direction of the wheel.

Total extent of steering-wheel movement. The performance means are plotted against ingested alcohol in Fig. 20 (for details of scoring see p. 29). The alcohol effect here is highly significant (Friedman: $P < \cdot 001$) and there is a suggestion that the relationship between steering-wheel movement and alcohol dose is curvilinear. The average extent of steering-wheel movement made in each period is given in Table 12.

TABLE 12

Mean steering-wheel movement in successive driving periods after drinking, for five doses

Driving period	Steering-wheel movement (arbitrary units) Dose 0 (Control)	Dose 1	Dose 2	Dose 3	Dose 4
1	716	711	757	756	821
2	665	688	684	717	774
3	662	650	659	680	746
4	653	642	661	681	715
Session mean	674	673	691	708	764

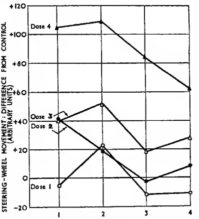

FIG. 21. Mean extent of steering-wheel movement (difference from control) in successive driving periods, for four doses of alcohol.

In Fig. 21 the mean differences in steering-wheel movement from control scores are plotted for each driving period for each dose. The rise and fall in the blood alcohol level is not so clearly reflected by the steering-wheel movement score as it is by tracking error. In particular, there is a disproportionately large increase in steering-wheel movement after alcohol in the first driving period. (Fig. 8 shows that this increase is already noticeable in the first five minutes of this period.) It will therefore be expected that the relation between mean blood alcohol level and mean steering-wheel movement will vary with time after

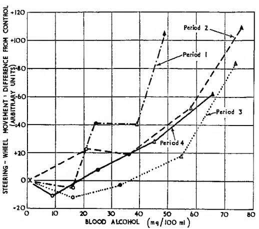

FIG. 22. The relation between mean extent of steering-wheel movement (difference from control) and mean blood alcohol in successive driving periods. (Dose symbols as in Fig. 21.)

drinking. This is illustrated in Fig. 22. The greatest effect is apparent over the four first driving periods, where an increase in blood alcohol results in the steepest increase in steering-wheel movement, the slopes for the four second, third, and fourth periods being rather more similar to each other. Because of this variation with time it is not appropriate to express the relationship between blood alcohol level and steering-wheel movement by a single function as is the case with tracking error.

Steering-wheel movement and tracking error are necessarily related, since the path of the 'car' is controlled only by movements of the steering-wheel. In Fig. 23 mean steering-wheel movement has been plotted against mean tracking error for control and for alcohol (all four doses combined). It can be seen that least error is caused by a medium amount of movement. Smaller and larger amounts produce more error, that is, a decrease in efficiency. With alcohol, subjects not only make larger amounts of movement than they do without but the amount of error associated with any given amount of movement is larger. A possible explanation is that the subjects misjudge the appropriate time at which to begin turning the steering-wheel.

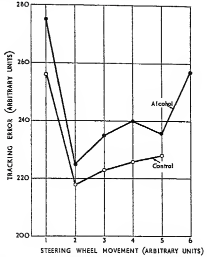

FIG. 23. The relation between mean tracking error and mean extent of steering-wheel movement for four alcohol doses combined and control dose.

With this machine, as with a real car, it is necessary to begin steering-wheel movements before a corner is actually reached. The records of 20 subjects for the whole session were analysed for the amount of anticipation of a double-bend corner under no-alcohol and dose four conditions. The results are given in Table 13 in terms of the distance from the corner (in arbitrary units) at which

TABLE 13

Mean anticipation of one corner under no-alcohol and alcohol conditions

Dose	No. of laps	Mean distance from corner at beginning of response (arbitrary units)	S.D.
Control . .	909	8·799	1·887
Dose 4 . .	854	8·685	2·232

the initial response to it was made. Though the mean timing of the response to this corner was hardly altered, variation about this mean increased. This was shown by an increase in the standard deviation.

This suggested that timing of initial response to this corner was affected; it seemed likely that, if this were so, the timing of the steering-wheel responses immediately following this response would also be affected and that this would be reflected in the consistency of steering-wheel movement.

Accordingly an examination was made of the average consistency of the subjects at seven positions on this corner, by a method similar to that used to analyse consistency in tracking performance. In this case the angular position of the steering-wheel at each of the seven positions on the corner in six successive laps was examined. The effects of alcohol were similar at the seven positions, so the scores were averaged for each dose. The results are shown in Table 14. It will be seen that there was decreasing consistency in steering-wheel positioning, but the trend is not statistically significant (Friedman: $P > \cdot 05$).

TABLE 14

Mean consistency score (steering-wheel positioning), for five doses

Dose 0 (Control)	Angular position of wheel (arbitrary score)			
	Dose 1	Dose 2	Dose 3	Dose 4
3·61	3·51	3·61	4·03	4·15

Reversals of direction of steering-wheel. So far the total extent of steering-wheel movement has been considered. The number of times the direction of rotation of the wheel was changed was also recorded in terms of (*a*) the total numbers of reversals made, (*b*) the number of reversals large enough to change the course of the car (effective reversals) and (*c*) 'hunting' movements too small to have this effect (ineffective reversals).

The effect of the different alcohol doses on the total number of reversals is shown in Fig. 24. After an initial reduction with the smallest dose, the number increases as the dose increases. The figure indicates that the relation between total number of reversals and alcohol dose may be curvilinear.

The total number of reversals includes both effective and ineffective ones; analysis shows that the alcohol doses have a significant effect only on the effective reversals (Friedman: $P < \cdot 05$). There are large individual variations in the numbers of ineffective, 'hunting', reversals made, but they are very largely a function of speed. An overall positive correlation of 0·69 ($P < \cdot 001$) exists between time per lap and number of 'hunting' movements. This means that a subject who drives slowly tends to 'hunt' with his steering-wheel. It is possible that this enables him to keep himself informed on the extent of backlash in the apparatus. A quicker driver has less time available in which to do this, so the number of such 'hunting' movements is reduced.

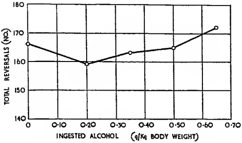

FIG. 24. Mean total reversals in direction of rotation of the steering-wheel for four doses of alcohol. (Each point is the mean of four driving period mean scores.)

Effective reversals alone are considered in Fig. 25, which shows that there is a slight decrease in activity for the smallest dose and an increase thereafter, that is, the relation between the number of reversals and alcohol dose may be non-linear.

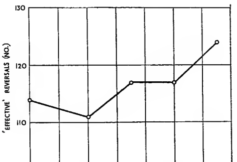

FIG. 25. Mean 'effective' reversals of the steering-wheel for four doses of alcohol. (Each point is the mean of four driving period mean scores.)

In Fig. 26 the differences in the number of effective reversals from control scores are plotted for each driving period for each dose. The maximum effect seems to be produced soon after drinking, as was the case with amount of steering-wheel movement (Fig. 21). This dependence of the alcohol effect on time after drinking is shown in Fig. 27 (cf. Fig. 22) where the steepest increase in effective reversals is seen to occur over the four first driving periods.

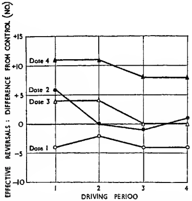

FIG. 26. Mean 'effective' reversals of the steering-wheel (difference from control) in successive driving periods, for four doses of alcohol.

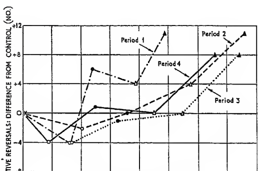

FIG. 27. The relation between mean 'effective' reversals of the steering-wheel (difference from control) and mean blood alcohol in successive driving periods. (Dose symbols as in Fig. 26.)

Summary. The effect of alcohol on steering-wheel movement may be summarized as follows:—

(*a*) There is an increase in the extent of steering-wheel movement after drinking alcohol. This increase is related to increase in amount ingested in a positively accelerated manner.

(*b*) Reversals of direction of rotation of the steering-wheel also increase after drinking alcohol, except after the smallest dose where a slight decrease occurs. This effect is also positively accelerated.

(*c*) Analysis of the effective and ineffective reversals separately shows that these trends are found only for those reversals which are effective in changing the course followed by the car; ineffective, 'hunting', movements of the wheel are not affected by alcohol.

(*d*) The rise and fall of blood alcohol with time is not closely reflected in the change in the amount of steering-wheel movement and in the incidence of reversals as is the case with tracking errors. Rather, the relationship between these measures and blood alcohol concentration is dependent on the time which has elapsed since the drink was taken. There is a greater effect in the first half-hour, while the blood alcohol level is rising.

(*e*) The relationship between the mean extent of steering-wheel movement made and the mean extent of tracking error which results is a U-function. There is some indication that alcohol not only increases the amount of movement but also affects timing of the responses.

Individual Differences

Although the effects of alcohol on performance have been discussed in terms of the group mean results, it is clear that there are considerable individual variations on every measure used. Reference to the analysis of variance (Appendix B) shows that subject variance has been highly significant in every analysis, i.e. subjects differed in their average level of performance on each measure.

Although these individual differences in the general level of performance of this task are of interest, this section is concerned with the variability in individual responses to alcohol.

The amount of practice at the task which preceded a given dose was not the same for all subjects, since they received the doses in one of five orders. In considering the group as a whole, dose order is balanced out, but, in order to assess the effect of alcohol on the individual, practice effect has to be taken into account for those performance measures in which it was found to be present for the group. The amount of change in score in any one trial to be expected from practice was obtained from the learning curve of the entire group, and an appropriate adjustment to his score under alcohol conditions was made for each individual. The variation in individual alcohol effects obtained in this manner was found to be virtually the same as that obtained by comparing the effects occurring within each of the five dose-order groups. Therefore the assumption implied in this correction for practice effects, that the practice effect is the same for each individual, does not distort the true picture: on the other hand, it enables comparisons to be made between the 40 subjects. No correction was made in the case of tracking error, since there was no appreciable practice effect with this score.

An overall score of alcohol effect for each individual was obtained from his scores for control and for the four alcohol doses by calculating the rate of change in performance with increasing doses of alcohol. To describe the alcohol effect for an individual the estimated change (difference from control score) at the dose 4 level has been taken from the resulting slope. Since the performance scores are in arbitrary units, the individual alcohol effects have been expressed as a percentage of the group mean control score.

Frequency distributions of individual differences in the direction and extent of the effect of alcohol are given in Table 15 for error, steering-wheel movement and time per lap (for speed). It can be seen that in each case there was a majority of the subjects showing more tracking error, more steering-wheel movement and slower speed after alcohol. In the case of speed the majority was very small; this reflects the lack of significance of the mean alcohol effect on speed. Ten subjects out of the 40 make less tracking error with alcohol than they do without, and eight make less steering-wheel movement. Of the ten making less error, seven drove more slowly after alcohol. Distribution of individual differences in consistency of tracking after alcohol showed that, of the 35 examined, eight became more consistent. Of these, six drove more slowly, and five of these also made less error. These five subjects, therefore, 'improved' after alcohol in that they drove more slowly, more consistently, and made less error. Of the 19 who drove more slowly, 12 nevertheless made more error.

TABLE 15

Numbers of subjects showing different percentage changes in score after alcohol (Dose 4), for three performance measures

Measure	Number of subjects											
	Per cent decrease in score					Per cent increase in score						
	−50	−40	−30	−20	−10	+10	+20	+30	+40	+50	+60	+70
Error . . .	1	—	2	2	5	10	12	4	2	2	—	—
Steering-wheel movement .	—	—	—	3	5	12	13	3	3	—	—	1
Time per lap .	—	—	—	5	11	13	5	2	—	—	—	—

Response to alcohol was related to a number of other variables in an attempt see if the individual differences could be explained. The variables were: level skill in operating the experimental apparatus, driving experience, age, sex, nking habits and certain personality characteristics.

Skill at the Task

For each of the three performance measures in Table 15 the eight subjects within each dose order group were divided according to their individual average score over five trials, into four high and four low scorers. They were also divided into two groups of four according to whether the effect of alcohol on their performance was large or small, and the results were then arranged in a 2 × 2 table. The numbers of individuals occurring in each quadrant were summed over the five sub-groups, and the resulting tables are given immediately below:—

		Alcohol effects		
		Small	Large	No.
Tracking error	High average .	9	11	20
	Low average .	11	9	20
	No.	20	20	40

		Alcohol effects		
		Time reduced	Time increased	No.
Time	High average .	9	11	20
	Low average .	11	9	20
	No.	20	20	40

		Alcohol effects		
		Small	Large	No.
Steering-wheel movement	High average .	10	10	20
	Low average .	10	10	20
	No.	20	20	40

For none of the performance measures is there a significant relation between the level of skill at the task and the effect of alcohol, as tested by chi square.

Driving Experience

Subjects were divided into three groups on the basis of driving experience. Group A (12 subjects) had an annual mileage of more than 5,000 miles. Ten subjects in this group owned a car and eight of them had held a driving licence for 15 years or more. Group B (13 subjects) had an annual mileage of from 2,000 to 4,000 miles; seven owned a car and nine had held a licence for from 4 to 15 years. Group C (15 subjects) had an annual mileage of less than 2,000 miles; 13 did not own a car and nine had held a driving licence for less than four years. The effect of alcohol is presented for these three groups in Table 16.

TABLE 16

Mean percentage change in performance after alcohol for five measures, for three groups differing in driving experience

Measure	Difference from control score (%)		
	Group A (12 subjects)	Group B (13 subjects)	Group C (15 subjects)
Tracking error	+ 10	+ 11	+ 8
Time per lap	− 1	+ 3	+ 1
Steering-wheel movement	+ 14	+ 5	+ 12
Inconsistency of car positioning	+ 8	+ 15	+ 24
Inconsistency of steering-wheel movement	+ 17	+ 8	+ 24

This table shows that only with regard to consistency of car positioning does there seem to be any relation between previous experience of driving and the effect of alcohol. The more experienced driver is more variable with alcohol than without, whereas the less experienced tends to be much more variable. This seems a reasonable result, and one which might be expected from Lewis' (1951) results. Even this, however, is not statistically significant. (Student's t: $P > \cdot 05$).

Age

The age distribution of the subjects has been given earlier (p. 15). It will be remembered that for 39 of the subjects the range was from 20–40; the remaining subject was aged 58. Correlating age with effect of alcohol for the three main measures gives

(*a*) Age and effect on tracking error . . . . . $r = -0 \cdot 265$
(*b*) Age and effect on speed . . . . $r = -0 \cdot 062$
(*c*) Age and effect on steering-wheel movement . . $r = +0 \cdot 075$

None of these correlations is significant. There is a slight tendency for the older subjects to show a smaller increase in error after alcohol, but within the range investigated in this experiment age cannot be said to be relevant.

Sex

There were no significant differences between the sexes in the effect of alcohol on any of the performance measures (Student's t: $P > \cdot 05$, in each case). However, it should be remembered that only five of the subjects were women.

Drinking Habits

The range of previous drinking habits of the subjects was very limited, as there were no heavy drinkers in the sample; however, the sample was divided into those who drank regularly once a week or more often and those who drank very rarely. The differences in alcohol effect on performance do not approach significance for any of the measures.

Personality

Product moment correlations were computed between the scores on the personality tests used in this study (listed on page 21) and the effects of alcohol for the various performance measures. In the first instance, eight performance variables were correlated with 32 personality measures (derived from all the tests listed on page 21 except the Maudsley Personality Inventory which was introduced later). Of the personality scores, 12 showed correlations with alcohol effects at greater than the 5 per cent level of significance. Ten of these were from tests which, according to their titles or to associations cited in the literature, would appear to be related to extraversion. The scores were derived from measures of aspiration level, of perception and of perseveration, from Porteus Maze performance, and from the Bernreuter Personality Inventory and the Minnesota Multiphasic Personality Inventory. However, the intercorrelations between these personality test scores themselves were low, despite the fact that each may be expected to measure extraversion, and it was therefore decided to re-examine the subjects by a test constructed specifically to measure extraversion —the Maudsley Personality Inventory. Thirty-five of the original forty subjects were available for re-testing. The sample seems to have been a reasonably balanced one on the extraversion-introversion scale: on a group of 400, Eysenck reported a mean score of 10·94 with a standard deviation of 4·74; the mean for the present sample was 10·24 with a standard deviation of 4·53.

That this test measures a general factor identified as extraversion by other investigators is supported by the fact that those scoring as extraverts performed on the driving task in the manner that would be expected from the results of previous investigations into the relation between performance and extraversion. People identified as extraverts have been shown to be relatively less concerned with accuracy of performance (Himmelweit, 1946), to deteriorate more rapidly during continuous work (Broadbent, 1956; Eysenck, 1957), and to be less consistent in performance (Venables, 1956). Such differences were found in the present study between the more extreme extraverts and introverts as identified by the Maudsley Scale. Nine of the subjects scored less than seven on this scale and seven subjects scored more than 14. Taking a score of less than seven to indicate introversion and one of more than 14 to indicate extraversion, a characteristic pattern emerges. Extraverts make more tracking error (by chi square $P < \cdot 05$), are less consistent in car positioning (by chi square $P < \cdot 05$), and show a bigger increase in error during each driving period than do introverts (by chi square $P < \cdot 01$).

The only correlation of the Maudsley Scale with response to alcohol which approached significance was that with tracking error ($r = +0{\cdot}34$ which is almost significant at the 5 per cent level). This correlation suggests that extraverts tend to be more impaired in their tracking skill than introverts; and the suggestion is supported by the fact that four of the other tests used as measures of extraversion gave correlations significant at this level with tracking error. In Fig. 28 the tracking error after alcohol compared with the error for control conditions is shown for extraverts and introverts for each driving period; the figure shows clearly the greater effect of alcohol on the tracking error of the extravert group.

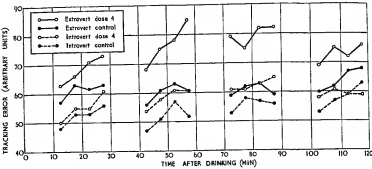

FIG. 28. Mean tracking error at different times after drinking, for one alcohol dose and control dose.

It can be seen that the extraverts tended to make rather more error than did the introverts under control, no-alcohol, conditions: after alcohol, whereas the introverts became somewhat less accurate, the extraverts showed a marked deterioration. For both groups the difference between the control and alcohol scores increases and decreases with rise and fall in blood alcohol, but again this is more clearly marked for extraverts than for introverts.

Whereas all seven extraverts showed a similar level of skill on the machine, the introvert group tended to be much less compact in performance; for tracking error, for example, the average score (for 5 doses) for the extraverts ranges from 213 to 321 units of error, while at the introvert end the scores range from 126 to 338. These tendencies can also be seen in the reactions to alcohol of the two groups; extraverts were affected by alcohol in a characteristic way, but the effect on the introverts was by no means as predictable.

A similar picture is obtained with speed scores. The majority of extraverts drive more quickly after alcohol, but the introvert group is again less compact, about half driving more quickly and the others more slowly. Moreover, the range of change in speed is very different for the two groups. Extraverts change their speed very little, five of the seven changing less than 5 per cent. Only one of the nine introverts showed as little change as this. The suggestion that with regard to speed of driving alcohol has more effect on introverts than on extraverts is strengthened when subjects are identified by the Bernreuter personality inventory rather than the Maudsley. (The neuroticism scale of the Bernreuter, which correlates almost perfectly with its introversion scale, was used in this experiment.) In Fig. 29 change in time per distance unit after alcohol (as a percentage change from control score) is plotted against Bernreuter rating. The extravert group (rather more numerous on this scale than on the Maudsley, but containing all seven of the Maudsley extraverts) tends to bunch around zero change. From about the middle of the scale up to the high scoring introverts, the distribution tends to bifurcate. The majority of subjects at this end change their speed markedly after alcohol; some speed up considerably and others show an equally large reduction in speed.

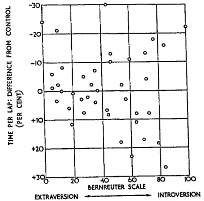

FIG. 29. Mean time per lap (difference from control) for Dose 4 plotted against extraversion measured by the Bernreuter Scale.

Plotting the amount of change irrespective of its direction gives an approximately linear increase in amount of change in speed after alcohol from the extravert to the introvert end (Fig. 30). The mean change in speed of those above the mid-point of the scale, i.e. the introvert group, is 13·9 per cent and the mean change for those below the mid-point, i.e. the extravert group, is 5·3 per cent.

The fact that the use of the Bernreuter scale produces a clearer picture of the greater effect of alcohol on the driving speed of introverts than that produced when the Maudsley scale is used may perhaps be explained in terms of the different concepts of introversion inherent in the two scales. Bernreuter uses a Freudian concept of the introvert as a near neurotic, whereas Eysenck adopts a more Jungian position which distinguishes fairly sharply between introversion and neuroticism. The same people are placed as extraverts on both these scales, but the introverts on the Maudsley scale are scattered about all over the Bernreuter scale.

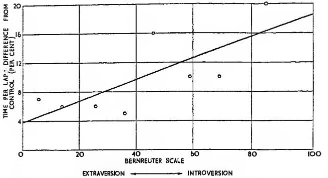

FIG. 30. Mean time per lap (difference from control) for Dose 4 plotted against extraversion measured by the Bernreuter Scale. (Each point is the mean of five subjects.)

Neither the Maudsley nor the Bernreuter scale distinguishes those introverts who speed up from those who slow down. The only indication about differences between the two groups comes from informal remarks about the subjects made by people who knew them. There was a tendency for those who slowed down to be described as normally cautious drivers and those who speeded up to be described as 'flighty'. No great weight can be placed on this evidence, but it seems to fit with the concept that drug action produces an exaggeration of normal personality characteristics (Steinberg, 1953).

None of the steering-wheel movement scores shows a significant relation to extraversion-introversion as measured by the Maudsley or Bernreuter scales. But the effect of alcohol on both extent of steering-wheel movement and inconsistency of movement is significantly correlated with the Hysteria score and with the Psychopathic Deviate score of the Minnesota Multiphasic Personality Inventory; $r = -0{\cdot}45$, $-0{\cdot}53$, $-0{\cdot}46$ and $-0{\cdot}44$ respectively (P in each case is greater than $\cdot 01$). That is to say, alcohol produces a greater increase in steering-wheel movement and a greater variability in operating the steering-wheel on those subjects who have low scores on these two tests.

It appears, then, that part at least of the individual variation found in response to alcohol can be explained in terms of personality differences. If the Maudsley scale is used to classify subjects as extraverts and introverts then it may be said that the tracking error scores of the extraverts are more seriously affected than those of the introverts. After alcohol, these scores show a clear and significant deterioration for the extraverts and a less clearly marked deterioration for the introverts. The effect of alcohol on speed, however, is greater for the introverts than for the extraverts. If the more 'neurotic' definition of introversion involved in the use of the Bernreuter scale is adopted, the difference between extraverts and introverts in terms of this effect on speed is emphasised.

Extraverts, then, may be said to respond to the stress imposed on them by alcohol by partially withdrawing from the problem. They do not appear to be unduly worried by it. Although markedly less accurate in their tracking, they 'drive' at much the same speed as before. Introverts, on the other hand, appear to be striving to compensate for the effect of alcohol and to demonstrate their efficiency. For one group of them, the criterion of efficiency seems to be slow, cautious driving and for the other group it seems to be rapid driving. The one group seems to be attempting to drive accurately, although driving more slowly does not always result in greater accuracy. The other group seems to be trying to demonstrate its efficiency by showing how fast it can drive; this increased speed usually, but not always, results in increased error.

The effects of alcohol on the steering-wheel movements of the introvert and extravert groups, as identified by the Maudsley scale, did not appear to differ. However, it was shown that high scorers on the Hysteria and Psychopathic Deviate scales of the Minnesota Multiphasic Personality Inventory differed from low scorers on these scales in the way alcohol affected control movements. Not only did the low scorers have a bigger increase in amount of steering-wheel movement, but their consistency of movement was more affected.

While none of the evidence presented in this section can be regarded as definitive, it suggests that some of the individual differences in response to alcohol can be explained in terms of personality structure and that one of the relevant dimensions is that of extraversion–introversion. However, the lack of agreement between the various scales used, and the differences in their relationships with the behaviour measures indicate that several other dimensions of personality in addition to the extraversion-introversion dimension are clearly relevant.

III. Discussion

It has been seen in the introduction that the literature concerning both laboratory studies and road accident figures reveals that a blood alcohol level of 150 mg% or more produces a serious, indeed dangerous, reduction in the efficiency with which an individual carries out a skilled task such as driving. The results of the present investigation demonstrate conclusively that for such complex skills impairment begins long before this level is reached.

The effects of several small doses of alcohol were measured and it is therefore possible to comment both on the shape of the dose/response curve and on the range of blood alcohol concentrations within which a threshold concentration in relation to impaired performance might lie.

In general, the performance scores were found to be increasingly affected as the alcohol dosage was raised. Previous work has suggested that a curvilinear relation exists between blood alcohol concentration and impairment of performance; Goldberg (1951), and Loomis and West (1958) suggest a logarithmic function. There is no evidence from the present results to suggest that within the range of blood alcohol concentration investigated the increase in tracking error is curvilinear, but it is possible that a different relationship exists at higher blood alcohol concentrations. In the case of the amount of steering-wheel movement made, the dose/response curve strongly suggests a curvilinear relationship.

The findings of previous investigators show different blood alcohol levels above which impaired performance begins; these findings imply that some alcohol may be present in the blood without performance being impaired. In the present study, at blood alcohol concentrations as low as 20 to 30 mg% the change in accuracy is in the same direction as the change following the larger concentrations. Therefore, if there is a threshold concentration below which performance remains unaffected, it will be below the concentration obtained for the lowest dose used in this experiment. Taking the group as a whole, there is on the average a measurable deterioration in performance when there is in the blood the smallest quantity of alcohol that can be detected by existing instruments.

The present study shows then that performance begins to deteriorate with very low blood alcohol concentrations, and that the deterioration is progressive, being related to blood alcohol level in a linear manner in the case of performance accuracy and probably in a curvilinear manner in the case of the amount of control movement made.

A general relationship between blood alcohol concentration and performance level has long been recognized, but it was shown in the Introduction that its closeness is dependent to some extent on three factors: the kind of behaviour studied, the time that has elapsed since the alcohol was consumed, and individual response to alcohol.

It has been shown that the effect of a given dose of alcohol will be different for different kinds of behaviour, and that more complex behaviour, mediated by higher brain centres, is likely to be affected earlier and to a greater extent than the more simple components of behaviour. Goldberg (1951) has pointed out that the blood alcohol level at which impairment is first noticed varies with the performance measured. Indeed this fact plays a part in producing the discrepancy between the levels of blood alcohol at which impairment is found in experimental investigations and the levels of blood alcohol associated with clinical intoxication. Experimental studies have shown impairment of skilled performance in subjects who showed no clinical signs of intoxication.

Previously impairment of skill following alcohol has usually been measured solely in terms of accuracy of overall performance (as judged by the final result). Welford (1958) suggests that 'very often the first signs of break down [in skill] will be that the component actions of a complex performance change while the overall achievement remains constant'. He stresses the importance of making 'as thoroughgoing an analysis as possible of the performance, in order to assess separately the functioning of the different mechanisms involved'. In the present experiment, although there was a clear effect of alcohol on overall performance, the effect on the controlling mechanism was even more clearly demonstrated. The rate of increase in steering-wheel movement with increasing doses was shown to be greater than the rate of increase in tracking error. It was thought that a possible explanation of this was that the timing of the steering-wheel movements was disturbed.

In the analysis of the results it appeared that timing of the initial steering response to a particular corner became increasingly variable with alcohol, and that there was an accompanying decrease in the consistency with which the subsequent steering-wheel movements necessary to negotiate the corner itself were made. The importance of timing of control movements in a complex skill has been stressed previously by Bartlett (1943), and adverse conditions such as fatigue have been shown to have a marked effect on timing (Drew, 1942, Davis, 1948).

Analysis of the error score for positioning of the car showed that after alcohol drivers spend less time towards the left-hand side of the road, and allow swings towards the right to go uncorrected for longer, while tending to correct swings towards the left rather sooner. A plausible hypothesis would seem to be that the subject is unwittingly simplifying his task as alcohol renders him less efficient. In a real car it is easier to be precise about the location of the driver's side than about the near side. In this apparatus the difference is exaggerated by the lack of definition of the 'near' kerb immediately in front of the near side front wheel. This makes it difficult to judge the precise distance of the car from the left hand kerb. As blood alcohol concentration rises, subjects appear to avoid this problem of judgement and to move over towards the right where they have a perceptually easier task. Bartlett's interpretation of his findings relating to simplification accompanying fatigue (1943) may be relevant to alcohol effect. He suggests that in setting his own standard of performance a subject will normally disregard errors below a critical size, though he will respond to errors above this size. In a fatigued state the subject will tolerate larger errors before he responds, his 'indifference range' is increased and he may therefore be under the impression that he is doing as well as usual, whereas, in fact, his error is greater.

The second factor which can affect the relation between blood alcohol level and performance change is that of the time which has elapsed since drinking.

Previous studies (discussed in the Introduction) have suggested that a blood alcohol level reached soon after the consumption of alcohol, and the same blood alcohol level achieved at a later time, will affect performance to different extents. The majority of these investigators have found that the effect is greater soon after ingestion, when blood alcohol concentration is rising. In the present instance, where performance was measured over a period of two hours, the effect of alcohol on tracking accuracy did not appear to depend to any great extent on this time factor. The fall of blood alcohol from the peak had not progressed far by the end of the 2-hour experimental period, but it was found that over this period there was a time lag of 5 to 10 minutes between the attainment of any given blood alcohol level and its resulting tracking error. This may be explained by a difference between the time at which any capillary blood level is reached, and the time at which its depressant effect is transmitted to the cells of the central nervous system. For periods of up to two hours, therefore, the relation between blood alcohol concentration and accuracy does not appear to be dependent on the time since ingestion. The effect of blood alcohol on level of steering-wheel activity, however, did appear to depend on this factor to a greater extent than can be accounted for by this time lag. For a given blood alcohol level there is a greater effect on steering-wheel movement in the first half-hour after ingestion than at later times. It seems reasonable to suppose that at the beginning of the task deliberate efforts are made to compensate for deficiencies in accuracy, but that these compensatory efforts are not maintained throughout the two hours.

More light is thrown on compensatory activity by a study of the individual differences in response to alcohol. These individual differences appear to be related, at least in part, to personality characteristics, especially those of extraversion–introversion. In this experiment subjects classified as extraverts appear not to be bothered by the extra stress imposed by alcohol. They drive at much the same speed as before but they make much more error. Those classified as introverts, on the other hand, appear to be striving to compensate for the alcohol effect, and to be anxious to demonstrate their efficiency. They over-react to the situation by changing their speed markedly. Some slow down, presumably in an attempt to achieve accuracy, although they do not necessarily do so, while others appear to be attempting to demonstrate how quickly they can drive, though not always with a proportionate loss of efficiency. This again is paralleled by the results of fatigue studies. If, as Eysenck's work suggests, the hysteria–anxiety dimension corresponds in clinical terms to the extraversion–introversion dimension, the findings of Davis (1948) in his 'cockpit' experiment on the effect of fatigue can be compared with those of the present experiment. Davis found that under fatigue-stress individuals classified as hysterics tended to respond by withdrawing and under-reacting, and those classified as anxiety-states tended to respond by over-reacting. This suggests that for both the extravert group and the introvert group the effect of alcohol is similar to that of fatigue.

While the emphasis in this investigation has been on the effect of alcohol on efficiency at a task resembling driving, the task used was almost completely free of hazard and risk-taking. From the point of view of driving in traffic the work of Cohen *et al.* (1958) adds interesting evidence; these authors have shown that an amount of alcohol not much larger than the biggest dose used in this experiment produced a significant increase in the risks which drivers took. From the two studies it is reasonable to assume that after taking an amount of alcohol roughly equivalent to the largest dose given in the present experiment, not only will drivers take greater risks than they would normally, but they will be less efficient in dealing with the hazardous situations which they bring about.

IV. Summary

(1) An experiment was carried out to investigate the effects of small doses of alcohol on performance at a task resembling driving.

(2) Records were made of the accuracy, speed, and handling of the driving controls of 35 male and 5 female drivers on the 'Miles Motor Driving Trainer' over a period of two hours on each of five occasions.

(3) On each occasion subjects received one of four alcohol doses or a placebo dose. The highest alcohol dose was equivalent to approximately three pints of 'average' beer or five fluid ounces of whisky, for a man of average weight. The concentration of alcohol in the blood and in the urine was assessed at half-hourly intervals following ingestion. The mean peak blood alcohol concentrations for the doses ranged from 20–80 mg%. After ingestion of each dose blood alcohol rose steeply, and reached its peak within 30–60 minutes. Thereafter it fell away more gradually at a constant rate. Urine alcohol curves were similar to blood alcohol curves, but the peaks were later and higher.

(4) Mean error increased significantly with increasing blood alcohol. With a blood alcohol concentration of some 80 mg% the deterioration in accuracy amounted to about 12 per cent. Part of the increase in error could be attributed to a tendency for subjects to move towards the right-hand side of the road, and part to less consistency in the manner with which the car was steered. The average error score rose and fell with time. The shape of the curve these changes produced was similar to that of the blood and urine alcohol curves, but changes in blood alcohol concentration anticipated by some ten minutes the changes in error score related to them, while changes in the urine alcohol concentration were related to the changes in error score that occurred some ten minutes earlier.

(5) The average speed at which subjects 'drove' showed no significant change with increasing blood alcohol.

(6) There was a significant increase in the mean amount of steering-wheel movement with increasing blood alcohol, and there were indications that this was due to a reduction in the accuracy and consistency with which steering-wheel movements were made.

(7) There were differences in the extent to which alcohol affected the accuracy, speed, and control handling of individual subjects.

(8) Within the limits of the sample, age, sex, previous drinking habits, skill at the experimental task, and amount of previous driving experience showed no relation to these individual differences in response to alcohol.

(9) Personality ratings, especially those relating to extraversion–introversion, showed a definite relation to behaviour changes. Extraverts did not alter

their speed of driving very much, but showed large increases in error. Introverts, on the other hand, showed considerable changes in speed, though some increased their speed and others decreased it. Although they showed considerable variation in the extent to which error increased, the mean change for introverts was less than that for extraverts.

(10) An investigation was made of the accuracy with which blood alcohol concentration could be estimated from urine alcohol concentration and from the results of different methods of breath analysis. (These results are given in Appendix A.)

Appendix A

An Evaluation of Urine and Breath Analysis for Estimating Blood Alcohol Content

METHOD

Urine and breath samples were collected at the time of blood sampling during this investigation in order to evaluate methods of estimating blood alcohol concentrations—at levels up to 100 mg%—from urine and breath alcohol concentrations.

The blood samples were taken by the pin-prick method. At each sampling approximately 0·5 ml was collected in a small pipette which had been previously sterilized and sealed. After collection of the sample, the pipette was resealed immediately. The pipettes contained preservatives as recommended by the British Medical Association (1954). Urine samples were put into sterile standard McCartney media bottles to which an appropriate preservative (British Medical Association, 1954) had been added. The blood and urine samples were analysed at the South-Western Forensic Science Laboratory.

The small amount of blood available necessitated the use of a micro-analytic technique, a modified Cavett method recommended by the British Medical Association Committee (Kent-Jones & Taylor, 1954). Although the same difficulty did not hold for urine samples, and the recommended Kozelka and Hine (macro) technique did not make the same demands on the analyst, it was nevertheless thought desirable to use the same analytic technique for both fluids to avoid possible complications arising from any differences in constant errors in the two methods. Duplicate analyses of every blood and urine sample were made, and the mean of the two results was used as the figure for alcohol concentration.

Breath samples were blown either into a balloon of standard resistance to inflation, or directly into a breath analysis apparatus, according to the designers' instructions.

The principles underlying the estimation of blood alcohol from breath alcohol are fully discussed by Harger, Forney & Barnes (1951). All methods work on the principle that the distribution of alcohol between alveolar breath and blood obeys Henry's law, but they differ mainly in the estimates of the correct ratio for this distribution and of the temperature which controls the final equilibrium between blood and breath (see Harger *et al.*, 1951). Four different instruments for the analysis of breath alcohol were made available by the Road Research Laboratory. One of these was not used; this was the Intoximeter (Jetter, Moore and Forrester, 1941), which provides a rapid check of whether enough alcohol is present to warrant a more detailed analysis. The three instruments that were used are designed to give accurate readings for the actual blood alcohol concentration. These three were: the Alcometer, developed by Greenberg & Keator (1941); the Drunkometer (Harger, Lamb & Hulpieu, 1938); and the Breathalyser (Borkenstein, 1956). The Drunkometer allows two methods of estimating breath alcohol, one based on the volume of breath used in the test and the other on the weight of carbon dioxide associated with the alcohol. Both methods were used here.

Not all subjects could be tested on all these methods of breath analysis. The subjects were tested as follows:—

Alcometer: Fifteen subjects were tested, from whom a total of 82 samples were obtained after they had drunk either dose 3 or dose 4.

Drunkometer: Two series of tests, each using both methods, were carried out with this instrument, with different subjects in the two series. Sixty-seven samples were obtained from six subjects in Series 1 and 58 from seven subjects in Series 2; samples were taken after all four doses but most of those taken after the lowest dose were useless as the breath concentration was below the point of minimum sensitivity of the apparatus.

Breathalyser: Two models of this instrument were tested, the first, a prototype, and the second, an improved production model. For the prototype a total of 131 samples were obtained, after all four doses, from 10 subjects; and for the improved model 103 samples after the two largest doses from 15 subjects.

RESULTS

The Relation between Blood and Urine Alcohol

It was noted in the main text of the report (page 28) that the urine alcohol curve rises more slowly to a peak which is higher than that for blood alcohol. The larger the dose, the larger the absolute discrepancy between the peak values. Once the urine peak has been passed, blood and urine alcohol curves run parallel. There is thus both a higher average alcohol concentration in the urine than in the blood and, since the urine concentration builds up more slowly, there is a lag between the time at which blood alcohol reaches any given level, and the time at which urine alcohol reaches the corresponding level. However, when adjustments are made for these two factors, blood and urine alcohol concentrations are seen to be very similar.

The first factor, the difference between blood and urine alcohol concentration is a constant one. A proportional difference may be expected on physiologica grounds, since alcohol is absorbed by body tissues and fluids in proportion t their water content (see p. 2). There is, however, some disagreement about th ratio. In this experiment the overall ratio of the alcohol concentration in the blood to that in the urine was found to be 1 : 1·25. This ratio was obtained when the bladder had been emptied before the alcohol was taken (tests made when alcohol was taken with the bladder full gave the ratio 1 : 1·12 (see p. 23)). Data given by Jetter (1938) yield a ratio of blood to urine alcohol of 1 : 1·32. The British Medical Association (1954) give the ratio as 1 : 1·33, and Taylor (1957) uses this figure. Elbel & Schleyer (1956) average the results of 15 authors and arrive at a figure of 1 : 1·27. Coldwell (1957) finds the ratio to be 1 : 1·24. All these blood/urine ratios are averages obtained at different times after drinking. However, since the concentration of alcohol in the bladder builds up more slowly than that in the blood, and also reaches a peak which is higher, it is clear that the ratio of alcohol in blood and urine must vary with time after drinking. In the present investigation the ratios found were:—

at 30 minutes ..	.. 1 : 0·93
60 minutes ..	.. 1 : 1·30
90 minutes ..	.. 1 : 1·36
120 minutes ..	.. 1 : 1·45

The second factor is the time lag between the blood and urine alcohol curves. Because of this lag the urine alcohol value at any given time after drinking is a poor indicator of the alcohol level in the blood at the same time, but it was found to reflect closely the blood alcohol level reached at an earlier time. It was found that the peak alcohol concentration is reached 20–25 minutes later in urine than in blood (see p. 28); since the samples were taken at 30-minute intervals a 30-minute adjustment was made; this brought the urine and blood figures closely into line.

When the urine alcohol values are reduced by 1/5th (because of the proportional difference) and matched with blood alcohol values found 30 minutes earlier (because of the time lag) it is found that the urine values approximate the blood alcohol values with an accuracy of ± 10·6 mg% (standard deviation); that is, in 95 out of 100 cases the true blood alcohol value will lie within ± 21 mg% of the adjusted urine alcohol value. The relationship is shown in Fig. A1, in which the urine values obtained at 60, 90 and 120 minutes have been reduced by 1/5th and moved back along the time scale by 30 minutes. It will be seen that this results in a very close approximation of the blood and urine curves.

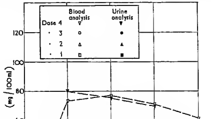

FIG. A1. The relation between mean blood alcohol and mean urine alcohol. (The urine values, reduced by one-fifth, have been brought forward by 30 minutes.)

The Relation between Blood Alcohol Values Determined by Breath Analysis and by Direct Blood Analysis

Since the breath analysis instruments were calibrated to give readings in terms of blood alcohol values, there should have been no need to allow for the constant difference between blood and breath alcohol. There was, however, found to be some error in all these instruments, but since the error was constant it could be allowed for, and therefore did not reduce the accuracy of the estimates of blood alcohol level.

The accuracy with which the breath instruments estimate the true blood alcohol level is shown in Table A1.* The values for urine alcohol are included for comparison. The accuracy is expressed both in terms of the standard deviation of the differences between the true and estimated blood values, and also in terms of the 95 per cent confidence limits, that is, the limits within which the true blood alcohol level will lie 95 times in 100. The constant error of the breath instrument readings is given in the last column. The relationship between the true blood analysis and the readings obtained from the different breath instruments is shown in Figs. A2–A8.

TABLE A1

Accuracy with which the different breath analysis instruments and urine alcohol estimate blood alcohol

Method of analysis	S.D.	95% limits of confidence	Constant Error
Drunkometer—			
Series 1, Volume method	22·4	± 45	+ 18
Series 1, Weight method	23·3	± 47	+ 12
Series 2, Volume method	13·1	± 26	− 4
Series 2, Weight method	11·5	± 23	− 15
Breathalyser—			
Prototype model	17·3	± 35	− 14
Production model	12·0	± 24	+ 2
Alcometer	20·1	± 40	− 22
Urine	10·6	± 21	+ 9

Drunkometer. For this instrument different constant errors were obtained in Series 1 from those obtained in Series 2; also within each series there was a difference between the constant errors obtained by the weight and volume methods of analysis. The constant error of the volume method in Series 2 is not significant so it was not necessary to make a constant correction for it. The results of the two series differ significantly from each other and therefore could not be combined; this casts a doubt on the reliability of the instrument. The only difference in conduct of the two series was that the chemical solution used in the measurement of breath alcohol was supplied by different firms. However, analyses of the two sets of solutions showed them to be chemically identical.

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*The breath instrument readings are given in Tables A3 to A9 at the end of this appendix, together with the corresponding values obtained by direct blood analysis.

Alcometer. The results obtained with this instrument were not good. Positive readings, indicating the presence of alcohol, were obtained for blank tests (without alcohol); the size of these readings varied not only from day to day but also throughout each experimental session. Best results were obtained by deducting a mean reading for the blank tests for any given day from the individual alcohol readings obtained on that day. The early results with this apparatus, apart from the positive readings for blanks, were very encouraging; on the first 24 paired values a correlation of + 0·892 was obtained. However, for the total of 82 readings the correlation dropped to + 0·386. This confirms other evidence suggesting that after the initial tests with this machine the accumulation of moisture in it adversely affected its reliability.

Breathalyser. The improved production model of this machine gave the best results of all the breath instruments, both as regards constant error, which was negligible, and accuracy of estimation of blood alcohol, which approached that for urine alcohol. There is no evidence that this apparatus is unreliable, as is the case with the other two instruments, and in particular it does not give positive readings for blank tests.

COMPARISON WITH OTHER INVESTIGATIONS OF INDIRECT METHODS OF BLOOD ALCOHOL ESTIMATION

A report of the Committee on Tests for Intoxication (1953), in which chemical tests for intoxication are evaluated, gives results for the Drunkometer, the Alcometer and the Intoximeter in a blood alcohol concentration range of

TABLE A2

Percentage distribution of the differences between values for blood alcohol determined by blood and by breath analysis in two studies

Blood/Breath difference (mg %)	American study		Present study	
	Drunkometer	Alcometer	Drunkometer	Breathalyser
0–5	25	34	31	38
6–10	31	26	24	26
11–15	25	24	24	18
16–20	15	13	5	7
21–25	2	3	8·5	7
26–30	2	—	3·5	2
31–35	—	—	3·5	1

0–200 mg%. Table A2 presents for comparison the accuracy of prediction by the Drunkometer and Alcometer in the American study and the Drunkometer and Breathalyser in the present study. It will be seen that the two investigations give similar results. In the American investigation both instruments had an accuracy, within 95 per cent confidence limits, of ± 22 mg%.

Coldwell (1957) has made a comparison of blood alcohol values measured by the Breathalyser and by direct analysis of blood. He found that the Breathalyser readings were accurate to ± 25 mg% at the 95 per cent confidence limits, which is very similar to the Breathalyser accuracy found in the present study. For the urine alcohol he found a predictive accuracy of ± 16 mg% at the 95 per cent level of confidence.

CONCLUSIONS

The readings of blood alcohol level obtained for the Drunkometer (Series 2) and Breathalyser are in close agreement with those obtained from direct blood analysis. The readings obtained from the Alcometer were accurate at first but afterwards became unreliable, possibly due to the accumulation of moisture in the apparatus.

The discrepancy between the Breathalyser or the Drunkometer readings and the true blood alcohol level will be less than 25 mg% 95 times in 100. The discrepancy between the adjusted urine alcohol level and blood alcohol level will be less than 20 mg% 95 times in 100.

TABLE A3

Blood alcohol levels estimated by direct blood analysis (x) *and by breath analysis with the Drunkometer—Series 1, Weight method* (y)

Ingested dose	Subject No.	Blood alcohol (mg%)							
		Sample							
		1		2		3		4	
		x	y	x	y	x	y	x	y
4	1	63	82	79	87	90	90	—	—
	2	35	49	66	62	60	66	63	62
	3	59	165	—	107	76	108	39	75
	4	102	81	74	92	69	117	63	129
	5	48	72	78	76	76	130	70	61
	6	—	—	88	77	87	76	—	—
3	1	43	58	51	59	54	61	51	61
	2	25	46	36	51	47	56	30	54
	3	73	69	73	99	61	163	50	69
	4	83	85	81	67	63	95	59	73
	5	50	69	72	59	68	48	53	48
	6	84	98	71	78	72	68	44	55
2	1	35	58	52	46	40	42	34	28
	2	23	41	39	44	31	27	—	—
	3	38	57	38	57	31	43	19	20
	4	22	—	39	34	56	29	30	21
	5	37	37	32	40	29	37	24	34
1	1	14	34	10	19	—	—	—	—
	3	26	31	18	20	—	—	—	—
	4	11	16	—	—	—	—	—	—

TABLE A4

Blood alcohol levels estimated by direct blood analysis (x) *and by breath analysis with the Drunkometer—Series 1, Volume method* (y)

Ingested dose	Subject No.	Blood alcohol (mg%)							
		Sample							
		1		2		3		4	
		x	y	x	y	x	y	x	y
4	1	63	75	79	89	90	85	—	—
	2	35	61	66	75	60	77	63	75
	3	59	150	—	118	76	113	39	77
	4	102	83	74	93	69	120	63	86
	5	48	86	78	87	76	150	70	135
	6	—	—	88	97	87	89	—	75
3	1	43	69	51	66	54	59	51	54
	2	25	59	36	58	47	67	30	64
	3	73	69	73	106	61	150	50	80
	4	83	100	81	75	63	108	59	85
	5	50	85	72	66	68	57	53	57
	6	84	92	71	75	72	69	44	61
2	1	35	59	52	53	40	35	34	26
	2	23	50	39	44	31	30	—	—
	3	38	61	38	60	31	43	19	17
	4	22	—	39	45	56	34	30	30
	5	37	66	32	59	29	47	24	42
1	1	14	41	10	20	—	—	—	—
	3	26	30	18	20	—	—	—	—
	4	11	24	—	—	—	—	—	—

TABLE A5

Blood alcohol levels estimated by direct blood analysis (x) *and by breath analysis with the Drunkometer—Series 2, Weight method* (y)

Ingested dose	Subject No.	Blood alcohol (mg%)							
		Sample							
		1		2		3		4	
		x	y	x	y	x	y	x	y
4	1	44	41	70	55	67	57	82	50
	2	66	51	87	57	67	51	61	44
	3	81	75	89	72	94	51	79	60
	4	63	54	79	59	66	61	63	54
	5	64	72	96	69	69	59	51	30
	6	68	69	89	65	68	59	64	50
	7	94	51	—	61	78	57	62	54
3	1	—	—	—	33	54	32	—	31
	2	62	51	56	47	25	—	18	—
	3	38	41	64	53	26	38	44	33
	4	59	30	63	32	44	25	29	26
	5	42	56	51	42	42	45	21	36
	6	51	45	70	47	55	37	35	23
2	1	23	17	—	19	44	17	18	—
	2	19	21	34	—	36	21	19	—
	3	44	41	42	24	—	26	14	—
	8	50	39	25	39	14	26	13	—
1	3	21	10	—	—	—	—	—	—
	5	18	16	25	18	—	—	—	—

TABLE A6

Blood alcohol levels estimated by direct blood analysis (x) *and by breath analysis with the Drunkometer—Series 2, Volume method* (y)

Ingested dose	Subject No.	Blood alcohol (mg%)							
		Sample							
		1		2		3		4	
		x	y	x	y	x	y	x	y
4	1	44	55	70	72	67	68	82	57
	2	66	57	87	69	67	62	61	58
	3	81	78	89	75	94	64	79	69
	4	63	56	79	65	66	61	63	55
	5	64	86	96	86	69	76	51	66
	6	68	81	89	72	68	63	64	56
	7	94	69	—	83	78	85	62	72
3	1	—	—	—	42	54	40	—	36
	2	62	57	56	58	25	—	18	—
	3	38	40	64	52	76	44	44	37
	4	59	40	63	37	44	32	29	30
	5	42	73	51	59	42	50	21	43
	6	51	53	70	55	55	42	35	30
2	1	23	21	—	23	44	23	18	—
	2	19	25	34	—	36	21	19	—
	3	44	43	42	32	—	26	14	—
	8	50	35	25	37	14	27	13	—
1	3	21	24	—	—	—	—	—	—
	5	18	18	25	20	—	—	—	—

TABLE A7

Blood alcohol levels estimated by direct blood analysis (x) *and by breath analysis, with the Breathalyser—Prototype model* (y)

Ingested dose	Subject No.	Blood alcohol (mg%)							
		Sample							
		1		2		3		4	
		x	y	x	y	x	y	x	y
4	1	62	46	60	64	99	61	73	48
	2	—	70	91	88	70	60	71	55
	3	68	53	89	59	68	69	64	48
	4	94	48	—	74	78	67	62	80
	5	91	51	90	29	95	15	85	46
	6	44	27	70	63	67	64	82	61
	7	66	36	87	44	67	55	61	47
	8	81	58	89	55	94	59	79	61
	9	63	35	79	53	66	59	63	40
	10	64	70	96	89	69	76	51	24
3	1	44	—	41	32	47	37	33	24
	2	88	50	66	50	51	58	49	—
	3	51	26	70	42	55	46	35	47
	4	53	59	61	74	46	34	29	32
	5	60	35	61	40	51	50	62	48
	6	—	11	—	29	54	36	—	28
	7	62	32	56	—	25	—	18	—
	8	38	21	64	28	76	29	44	30
	9	59	18	63	26	44	27	29	—
	10	42	44	51	56	42	46	21	58
2	1	29	16	42	29	20	22	9	18
	2	50	41	25	32	14	31	13	26
	3	29	13	53	12	48	8	26	11
	4	56	27	40	32	23	37	17	26
	6	23	24	—	18	44	26	18	20
	7	19	12	34	21	36	26	19	14
	8	44	18	42	19	—	22	14	10
	10	19	18	41	20	37	22	28	28
1	1	20	5	11	7	11	8	4	3
	3	—	—	—	—	—	4	—	—
	4	38	20	19	7	16	—	6	9
	5	28	—	33	—	40	—	1	18
	6	6	8	—	—	1	—	2	—
	7	10	—	22	2	10	10	—	—
	8	21	—	21	14	14	—	—	10
	9	23	—	32	—	5	—	—	3
	10	18	—	25	5	9	3	6	23

TABLE A8

Blood alcohol levels estimated by direct blood analysis (x) *and by breath analysis with the Breathalyser—Production model* (y)

Ingested dose	Subject No.	Blood alcohol (mg%)															
		Sample															
		1		2		3		4		5		6		7		8	
		x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y
4	1	74	84	80	105	93	97	84	83	101	92	79	82	78	84	75	67
	2	56	68	78	84	67	75	88	76	72	78	64	71	64	79	76	71
	3	88	86	60	77	56	66	47	61	63	59	75	50	—	—	—	—
	4	49	74	68	72	62	76	74	77	76	61	75	59	60	62	56	61
	5	61	61	68	55	90	70	75	72	84	87	61	75	—	—	—	—
	6	53	77	60	90	73	91	76	77	82	87	55	83	70	81	62	66
	7	76	76	70	77	71	78	92	90	83	82	83	84	63	74	84	73
	8	64	71	61	94	67	82	76	76	71	79	86	73	80	79	—	—
3	9	48	63	60	70	70	70	43	42	63	45	60	38	—	—	—	—
	10	49	50	52	54	58	68	57	48	56	49	—	—	—	—	—	—
	11	68	46	50	51	69	55	58	51	44	35	—	—	—	—	—	—
	12	50	51	56	73	68	62	66	62	48	62	54	54	52	52	—	—
	13	86	77	87	81	85	83	89	70	75	70	64	60	47	58	—	—
	14	49	48	61	67	71	65	72	50	64	51	37	38	—	—	—	—

TABLE A9

Blood alcohol levels estimated by direct blood analysis (x) *and by breath analysis with the Alcometer* (y)

Ingested dose	Subject No.	Blood alcohol (mg%)															
		Sample															
		1		2		3		4		5		6		7		8	
		x	y	x	y	x	y	x	y	x	y	x	y	x	y	x	y
4	1	74	100	80	103	93	109	84	100	101	101	79	81	78	77	75	72
	2	56	52	78	65	67	64	88	69	72	70	64	71	64	71	76	67
	3	88	32	60	45	56	41	47	32	63	34	75	36	—	—	—	—
	4	49	41	68	59	62	52	74	41	76	55	75	56	60	56	56	51
	5	61	34	68	27	90	39	75	31	84	59	61	67	—	—	—	—
	6	53	25	73	29	76	33	82	33	70	34	62	29	—	—	—	—
	7	76	39	71	36	92	40	83	31	84	32	—	—	—	—	—	—
	8	64	20	67	36	71	43	86	41	80	40	—	—	—	—	—	—
3	9	48	61	60	64	70	56	43	38	63	46	60	35	—	—	—	—
	10	49	21	52	30	58	25	57	43	56	45	—	—	—	—	—	—
	11	68	28	50	40	69	39	58	37	44	40	—	—	—	—	—	—
	12	50	26	68	29	66	31	54	41	—	—	—	—	—	—	—	—
	13	86	35	85	39	89	33	64	30	47	28	—	—	—	—	—	—
	14	49	16	71	33	72	21	64	24	37	23	—	—	—	—	—	—

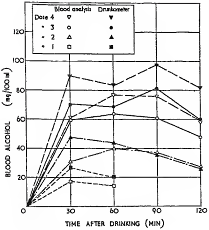

FIG. A2. Blood alcohol levels as given by direct blood analysis and by the Drunkometer (Weight method), Series 1, for four doses.

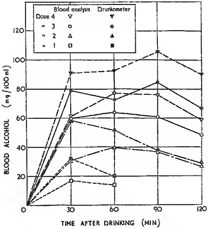

FIG. A3. Blood alcohol levels as given by direct blood analysis and by the Drunkometer (Volume method), Series 1, for four doses.

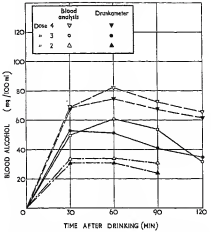

FIG. A4. Blood alcohol levels as given by direct blood analysis and by the Drunkometer (Weight method), Series 2, for three doses.

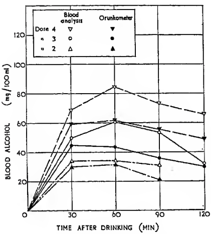

FIG. A5. Blood alcohol levels as given by direct blood analysis and by the Drunkometer (Volume method), Series 2, for three doses.

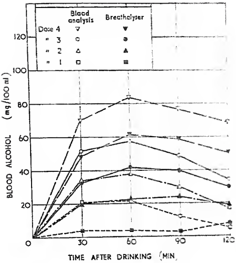

FIG. A6. Blood alcohol levels as given by direct blood analysis and by the Breathalyser, Prototype model, for four doses.

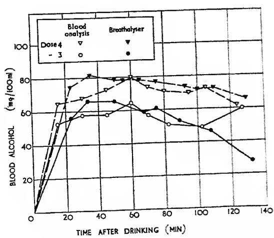

FIG. A7. Blood alcohol levels as given by direct blood analysis and by the Breathalyser, Production model, for two doses.

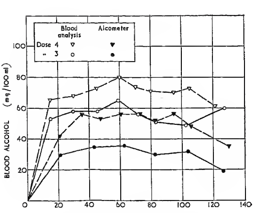

FIG. A8. Blood alcohol levels as given by direct blood analysis and by the Alcometer, for two doses.

Appendix B

Summary of Analysis of Variance of Main Scores

These tables are abridged. They show the statistical significance of the effects (on session mean scores) of some of the main factors in the experiment.

TABLE B1

Analysis of variance of tracking error scores

Source of Variation	df	Mean square	Tested against	F
1 Dose Level	4	12,264	(4)	3·66*
2 Day	4	1,958	(5)	<1·00
3 Subject	39	56,826	(6)	25·48***
4 Dose Level × Latin Square	28	3,348	(6)	1·50
5 Day × Latin Square	28	4,027	(6)	1·81*
6 Residual	96	2,230	—	—
TOTAL	199	—	—	—

*P<·05
***P<·001

TABLE B2

Analysis of variance of time scores

Source of Variation	df	Mean square	Tested against	F
1 Dose Level	4	7,220	(4)	1·03
2 Day	4	185,158	(5)	25·72***
3 Subject	39	153,313	(6)	27·38***
4 Dose Level × Latin Square	28	6,987	(6)	1·25
5 Day × Latin Square	28	7,200	(6)	1·29
6 Residual	96	5,600	—	—
TOTAL	199	—	—	—

***P<·001

TABLE B3

Analysis of variance of steering-wheel movement scores

Source of Variation	df	Mean square	Tested against	F
1 Dose Level	4	225,794	(4)	12·94***
2 Day	4	328,420	(5)	8·81***
3 Subject	39	273,505	(6)	16·90***
4 Dose Level × Latin Square	28	17,453	(6)	1·08
5 Day × Latin Square	28	37,263	(6)	2·30***
6 Residual	96	16,178	—	—
TOTAL	199	—	—	—

***P<·001

TABLE B4

Analysis of variance of total reversals of the steering-wheel

Source of Variation	df	Mean square	Tested against	F
1 Dose Level	4	3,893	(4)	3·77*
2 Day	4	21,550	(5)	20·92***
3 Subject	39	25,580	(6)	23·15***
4 Dose Level × Latin Square	28	1,032	(6)	<1·00
5 Day × Latin Square	28	1,030	(6)	<1·00
6 Residual	96	1,105	—	—
TOTAL	199	—	—	—

*P<·05
***P<·001

TABLE B5

Analysis of variance of effective reversals of the steering-wheel

Source of Variation	df	Mean square	Tested against	F
1 Dose Level	4	3,491	(4)	6·83***
2 Day	4	7,150	(5)	18·76***
3 Subject	39	8,559	(6)	17·22***
4 Dose Level × Latin Square	28	511	(6)	1·02
5 Day × Latin Square	28	381	(6)	<1·00
6 Residual	96	497	—	—
TOTAL	199	—	—	—

***P<·001

TABLE B6

Analysis of variance of ineffective reversals of the steering-wheel

Source of Variation	df	Mean square	Tested against	F
1 Dose Level	4	489	(4)	1·82
2 Day	4	3,956	(5)	9·74***
3 Subject	39	6,737	(6)	20·54***
4 Dose Level × Latin Square	28	269	(6)	<1·00
5 Day × Latin Square	28	406	(6)	1·23
6 Residual	96	328	—	—
TOTAL	199	—	—	—

***P<·001

Appendix C

Tables of Individual Blood and Urine Alcohol Readings and Performance Scores

TABLE C1

Blood alcohol levels (mg alcohol per 100 ml blood)

DOSE 1

(0·20g. alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	17	19	20	6
	2	21	29	20	9
	3	20	28	15	3
	4	25	15	6	5
	5	22	14	9	1
2	6	30	8	3	0
	7	22	9	9	3
	8	23	15	9	5
	9	18	6	3	0
	10	17	12	5	3
3	11	30	7	2	0
	12	28	14	7	9
	13	32	25	15	6
	14	39	16	9	5
	15	17	14	22	5
4	16	32	21	17	12
	17	36	36	26	22
	18	30	25	7	6
	19	30	9	10	10
	20	22	20	20	10
5	21	14	10	9	0
	22	10	18	12	5
	23	26	18	10	4
	24	11	16	13	11
	25	16	13	24	6
6	26	22	30	10	0
	27	18	32	27	22
	28	6	7	1	1
	29	13	31	25	2
	30	60	46	29	4
7	31	20	11	11	19
	32	28	15	8	7
	33	23	18	11	7
	34	38	19	16	6
	35	28	33	40	1
8	36	6	10	1	2
	37	10	22	11	0
	38	21	21	14	4
	39	23	32	5	0
	40	18	25	9	6
Mean		23	19	13	6
S.D.		10	9	8	5

(*continued on* p. 87)

TABLE C1—*(continued)*

Blood alcohol levels (mg alcohol per 100 ml blood)

DOSE 2

(0·35g alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	48	41	30	20
	2	40	36	27	17
	3	43	36	29	24
	4	34	26	21	21
	5	37	34	29	21
2	6	71	48	36	30
	7	38	41	37	12
	8	29	22	18	14
	9	36	23	19	16
	10	29	34	24	16
3	11	46	35	34	21
	12	50	47	29	15
	13	8	26	29	16
	14	22	26	34	25
	15	45	35	29	19
4	16	45	40	38	35
	17	42	37	31	38
	18	86	68	52	51
	19	54	41	31	32
	20	23	28	36	18
5	21	35	52	40	34
	22	23	39	31	23
	23	38	38	31	19
	24	22	39	56	30
	25	37	32	29	24
6	26	20	30	29	19
	27	11	20	13	7
	28	52	65	32	26
	29	41	37	22	19
	30	30	33	22	22
7	31	29	42	20	9
	32	50	25	14	13
	33	29	53	39	19
	34	56	40	23	17
	35	19	40	30	15
8	36	23	30	44	18
	37	19	34	36	19
	38	44	42	25	14
	39	27	20	21	0
	40	19	41	37	28
Mean		36	37	30	20
S.D.		15	10	9	9

(continued on p. 88)

TABLE C1—(*continued*)

Blood alcohol levels (mg alcohol per 100 ml blood)

DOSE 3

(0·50g alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	63	55	47	40
	2	56	59	73	39
	3	67	50	37	35
	4	64	62	68	43
	5	46	41	29	19
2	6	71	68	55	56
	7	60	73	74	51
	8	65	60	56	33
	9	51	34	36	24
	10	64	40	40	39
3	11	58	55	44	41
	12	56	52	47	43
	13	90	76	40	27
	14	82	60	48	41
	15	56	63	54	48
4	16	64	61	55	35
	17	57	71	54	49
	18	62	57	48	34
	19	63	57	56	46
	20	84	71	72	44
5	21	43	51	54	51
	22	25	36	47	30
	23	73	73	61	50
	24	83	81	63	59
	25	50	72	68	53
6	26	53	66	57	51
	27	55	53	37	35
	28	61	65	47	35
	29	46	52	40	35
	30	46	49	42	40
7	31	40	41	47	33
	32	88	66	51	49
	33	51	70	55	35
	34	53	61	46	29
	35	60	61	62	51
8	36	25	45	54	36
	37	62	56	26	18
	38	38	64	76	44
	39	59	63	44	29
	40	42	51	42	21
Mean		58	59	51	39
S.D.		14	11	12	10

(*continued on* p. 89)

TABLE C1—*(continued)*

Blood alcohol levels (mg alcohol per 100 ml blood)

DOSE 4

(0·65g alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	102	72	68	47
	2	97	89	92	85
	3	85	82	60	50
	4	86	66	59	55
	5	80	82	63	56
2	6	100	86	85	68
	7	60	79	73	71
	8	82	71	54	50
	9	82	60	46	37
	10	86	78	70	68
3	11	83	81	71	74
	12	69	73	76	37
	13	41	62	52	37
	14	79	74	68	53
	15	82	60	67	55
4	16	71	80	79	74
	17	93	89	91	70
	18	70	63	37	34
	19	73	64	67	55
	20	92	88	67	87
5	21	63	79	90	84
	22	36	66	60	63
	23	59	67	76	39
	24	101	74	69	63
	25	48	78	76	70
6	26	56	63	54	41
	27	120	104	88	85
	28	58	79	77	69
	29	44	57	58	40
	30	66	98	68	69
7	31	62	60	99	73
	32	70	91	70	71
	33	68	89	68	64
	34	94	85	78	62
	35	91	90	95	82
8	36	44	70	67	82
	37	66	87	67	61
	38	81	89	94	79
	39	62	79	66	63
	40	64	96	69	52
Mean		74	77	71	62
S.D.		19	12	14	15

TABLE C2

Urine alcohol levels (mg alcohol per 100 ml urine)

DOSE 1

(0·20g alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	16	13	1	1
	2	30	39	17	2
	3	35	19	17	10
	4	23	18	11	7
	5	21	25	10	3
2	6	24	31	24	10
	7	18	27	19	13
	8	25	21	14	6
	9	21	20	10	3
	10	22	22	14	2
3	11	31	33	9	0
	12	20	23	25	17
	13	19	25	22	11
	14	30	27	16	5
	15	25	24	12	1
4	16	16	19	24	21
	17	20	29	30	21
	18	19	25	15	9
	19	30	23	12	9
	20	17	29	20	8
5	21	7	12	15	12
	22	6	13	12	7
	23	9	25	14	2
	24	12	23	22	4
	25	7	14	23	4
6	26	15	20	3	3
	27	9	17	10	4
	28	12	16	10	3
	29	13	16	8	3
	30	52	56	35	12
7	31	15	25	13	4
	32	29	41	25	8
	33	19	23	16	7
	34	32	34	30	15
	35	32	26	17	1
8	36	6	10	12	2
	37	0	4	24	0
	38	7	16	7	6
	39	18	21	19	13
	40	10	22	11	6
Mean		19	23	16	7
S.D.		10	9	12	5

(*continued on* p.91)

TABLE C2—(*continued*)

Urine alcohol levels (mg alcohol per 100 ml urine)

DOSE 2

(0·35g alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	43	40	33	26
	2	38	46	36	27
	3	46	50	36	29
	4	33	36	26	11
	5	28	43	33	28
2	6	78	75	57	39
	7	11	45	48	40
	8	23	36	27	18
	9	55	42	28	19
	10	22	43	39	31
3	11	59	70	43	33
	12	41	53	43	28
	13	4	26	27	31
	14	47	48	39	27
	15	34	51	40	38
4	16	30	38	40	36
	17	34	51	46	38
	18	71	91	77	75
	19	63	54	43	38
	20	29	37	39	31
5	21	34	64	58	46
	22	17	43	39	28
	23	21	51	47	33
	24	13	45	48	30
	25	25	49	45	42
6	26	21	43	41	24
	27	14	38	39	34
	28	48	54	46	35
	29	52	71	45	30
	30	41	44	37	26
7	31	33	48	37	24
	32	49	57	47	28
	33	39	54	48	26
	34	58	59	40	31
	35	19	45	42	35
8	36	32	20	50	24
	37	13	32	29	31
	38	42	50	44	38
	39	30	32	17	4
	40	23	44	43	39
Mean		35	48	41	31
S.D.		17	13	10	10

(*continued on* p. 92)

TABLE C2—(*continued*)

Urine alcohol levels (mg alcohol per 100 ml urine)

DOSE 3

(0·50g alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	51	74	65	54
	2	63	84	84	76
	3	78	75	63	59
	4	81	72	66	51
	5	32	54	33	20
2	6	56	97	82	76
	7	51	82	84	82
	8	54	80	68	56
	9	64	80	57	53
	10	64	70	64	55
3	11	56	63	58	51
	12	46	67	65	58
	13	49	76	68	63
	14	71	86	71	60
	15	63	78	75	63
4	16	43	53	56	66
	17	54	80	84	74
	18	48	83	76	60
	19	80	80	71	64
	20	96	93	88	69
5	21	38	64	75	62
	22	12	49	54	49
	23	77	95	86	73
	24	60	105	90	70
	25	45	87	81	68
6	26	76	92	78	68
	27	29	75	77	63
	28	58	71	69	59
	29	80	83	72	54
	30	66	76	69	55
7	31	39	59	53	42
	32	89	103	100	71
	33	49	82	76	65
	34	60	80	74	61
	35	51	78	70	64
8	36	11	40	49	48
	37	69	64	40	32
	38	34	67	64	51
	39	56	78	76	70
	40	50	73	74	56
Mean		56	76	70	60
S.D.		18	14	9	12

(*continued on* p. 93)

TABLE C2—(*continued*)

Urine alcohol levels (mg alcohol per 100 ml urine)

DOSE 4

(0·65g alcohol per Kg body weight)

Square	Subject No.	Time after ingestion (min)			
		30	60	90	120
1	1	51	94	81	68
	2	31	91	100	97
	3	99	104	99	83
	4	93	100	87	76
	5	83	96	84	84
2	6	63	131	121	109
	7	30	108	125	119
	8	95	113	105	84
	9	119	94	80	68
	10	82	111	93	86
3	11	84	104	93	91
	12	73	86	89	81
	13	29	62	71	78
	14	69	99	100	88
	15	71	87	77	68
4	16	80	99	105	103
	17	82	115	109	103
	18	80	89	71	66
	19	85	81	75	70
	20	105	115	110	101
5	21	67	98	101	93
	22	17	63	83	79
	23	56	110	101	90
	24	80	116	103	84
	25	44	92	96	88
6	26	42	80	63	52
	27	121	150	125	116
	28	57	90	92	88
	29	36	85	82	67
	30	53	108	102	97
7	31	33	96	93	77
	32	70	112	105	87
	33	49	112	104	91
	34	78	100	100	94
	35	66	123	115	105
8	36	22	75	84	80
	37	50	109	107	91
	38	41	121	109	97
	39	72	92	83	78
	40	95	136	128	109
Mean		66	101	96	87
S.D.		26	18	15	14

TABLE C3

*Tracking error scores**

Period	Square 1					Square 2					Square 3					Square 4				
	Day					Day					Day					Day				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Subject 1					Subject 6					Subject 11					Subject 16				
1	124	135	130	195	139	328	286	270	249	272	224	226	144	197	132	194	260	215	184	207
2	150	153	160	194	163	297	272	246	292	269	235	241	175	193	118	180	232	229	214	213
3	152	169	143	178	168	316	299	260	269	259	209	211	147	181	114	203	252	216	207	221
4	162	120	143	184	182	311	303	282	289	234	202	194	133	178	133	204	214	238	200	176
	Subject 2					Subject 7					Subject 12					Subject 17				
1	251	179	218	241	236	257	298	228	212	189	281	347	259	251	271	282	208	222	206	225
2	257	222	260	254	232	292	297	240	213	176	335	300	245	269	227	303	249	291	246	263
3	272	272	281	235	228	345	362	262	250	188	267	292	235	250	239	292	297	285	280	260
4	279	242	279	241	257	363	360	253	239	222	324	354	239	252	232	314	284	270	273	276
	Subject 3					Subject 8					Subject 13					Subject 18				
1	254	184	182	199	186	193	246	242	290	327	192	197	202	126	133	239	248	269	260	256
2	224	194	178	193	208	201	227	325	367	308	190	181	142	139	173	284	236	279	247	260
3	216	163	181	232	206	191	218	343	312	290	144	197	210	159	190	310	249	262	237	315
4	210	160	185	250	268	232	299	422	322	316	174	201	202	211	177	291	260	274	243	276
	Subject 4					Subject 9					Subject 14					Subject 19				
1	225	185	246	276	286	227	244	267	262	268	172	143	194	142	155	282	226	271	169	268
2	205	228	266	290	306	218	287	293	284	266	151	171	201	168	201	277	241	232	200	279
3	211	245	272	283	299	238	312	305	274	275	143	190	191	181	221	244	246	231	221	267
4	215	264	252	266	288	253	294	325	285	272	168	187	165	188	214	274	222	251	224	243
	Subject 5					Subject 10					Subject 15					Subject 20				
1	304	317	353	397	370	274	255	300	302	296	311	232	292	232	264	183	135	127	93	91
2	299	344	323	419	301	276	303	350	299	296	242	216	226	279	217	176	120	115	120	95
3	286	284	340	351	370	263	310	398	327	296	237	247	281	263	232	180	134	115	114	102
4	309	314	340	388	368	327	301	329	338	310	247	232	279	277	276	179	111	132	121	86

(continued on p. 95)

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* For method of scoring see p. 29.

TABLE C3—(*continued*)

*Tracking error scores**

Period	Square 5					Square 6					Square 7					Square 8				
	Day 1	2	3	4	5	Day 1	2	3	4	5	Day 1	2	3	4	5	Day 1	2	3	4	5
	Subject 21					Subject 26					Subject 31					Subject 36				
1	242	225	207	214	189	157	120	161	128	168	262	260	238	235	224	229	218	243	209	155
2	236	255	213	246	208	130	108	148	131	178	271	274	252	233	236	209	227	225	208	193
3	280	242	230	240	196	119	136	177	168	187	280	283	249	239	250	229	277	219	223	190
4	263	249	219	228	197	111	146	184	186	188	294	268	261	267	223	248	273	215	211	214
	Subject 22					Subject 27					Subject 32					Subject 37				
1	268	294	327	328	304	185	260	316	308	319	156	170	162	128	162	265	291	246	242	260
2	260	319	327	318	329	178	328	295	326	316	159	187	162	147	160	249	276	283	241	252
3	243	325	321	324	348	219	339	302	348	323	173	187	154	149	151	246	262	259	250	225
4	272	341	313	315	325	219	364	314	368	324	158	195	161	129	216	269	247	242	242	236
	Subject 23					Subject 28					Subject 33					Subject 38				
1	159	159	160	181	198	227	210	230	237	207	335	244	295	194	229	265	266	222	200	190
2	154	158	171	188	178	212	211	233	268	230	263	228	268	265	228	248	236	222	233	239
3	154	150	160	188	186	234	238	242	281	228	210	255	266	248	256	272	224	216	244	247
4	140	150	149	190	179	230	227	229	257	192	233	223	300	201	258	267	215	204	232	233
	Subject 24					Subject 29					Subject 34					Subject 39				
1	209	237	231	269	224	243	205	217	228	236	278	372	309	269	315	250	280	315	313	246
2	195	231	260	175	216	208	196	224	252	256	311	283	308	292	285	257	303	321	338	268
3	174	234	202	207	307	236	199	242	227	303	328	290	318	317	324	311	309	319	299	296
4	170	216	192	176	240	236	215	212	240	263	341	288	323	311	333	304	335	328	309	306
	Subject 25					Subject 30					Subject 35					Subject 40				
1	163	163	221	167	137	184	156	136	157	187	279	326	322	315	272	175	197	207	205	209
2	172	161	218	152	127	170	154	152	150	183	293	341	419	316	263	240	185	181	212	202
3	181	190	222	163	149	162	165	158	146	204	327	377	425	292	258	234	226	214	205	214
4	176	141	202	183	139	155	156	153	152	163	297	394	304	329	272	246	210	196	207	227

* For method of scoring see p. 29.

TABLE C4

*Time scores**

Period	Square 1					Square 2					Square 3					Square 4				
	Day					Day					Day					Day				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
			Subject 1					Subject 6					Subject 11					Subject 16		
1	570	558	584	619	574	414	449	459	460	428	458	442	410	414	416	578	404	427	397	368
2	575	543	563	579	569	363	451	462	439	403	475	429	382	384	393	581	409	373	365	334
3	545	536	599	572	567	300	486	448	434	303	462	389	358	360	401	533	399	367	385	341
4	548	529	597	592	537	288	479	451	420	422	451	414	405	358	405	487	393	349	380	356
			Subject 2					Subject 7					Subject 12					Subject 17		
1	359	326	319	298	259	349	423	384	358	350	428	336	327	320	284	394	387	382	391	340
2	309	278	252	282	259	327	336	336	280	299	330	390	358	269	320	358	330	347	313	299
3	305	274	256	281	257	311	316	322	233	293	431	392	360	292	363	349	310	317	294	287
4	294	288	268	273	249	324	309	305	232	303	378	312	349	350	331	290	387	317	276	296
			Subject 3					Subject 8					Subject 13					Subject 18		
1	441	422	456	530	474	532	578	523	470	400	541	455	365	465	386	355	301	306	358	300
2	439	402	427	450	398	496	603	461	381	449	513	404	335	444	304	315	326	290	390	281
3	433	406	397	389	336	497	594	382	400	412	465	380	355	403	315	319	291	286	372	277
4	434	395	411	335	327	510	471	332	423	366	502	340	327	378	310	312	266	288	352	284
			Subject 4					Subject 9					Subject 14					Subject 19		
1	514	494	635	346	319	587	451	344	281	328	488	423	443	411	417	783	797	681	616	568
2	431	366	582	366	290	459	317	232	227	274	451	404	420	406	401	816	716	631	616	549
3	410	291	376	378	306	387	272	295	265	235	442	404	414	395	391	804	682	651	584	562
4	376	266	274	298	266	310	248	218	212	280	438	400	415	400	406	865	650	663	611	498
			Subject 5					Subject 10					Subject 15					Subject 20		
1	255	232	230	226	301	444	365	383	323	268	369	376	367	387	301	581	457	579	573	488
2	232	219	223	233	277	337	306	239	292	229	418	381	470	349	302	500	438	569	552	483
3	217	217	228	232	249	336	314	215	233	257	416	369	432	337	279	481	419	610	544	447
4	228	216	228	220	256	299	285	251	223	274	411	348	429	294	290	433	405	560	506	450

* For method of scoring see p. 29.

(continued on p. 97)

TABLE C4—(*continued*)

*Time scores**

Period	Square 5					Square 6					Square 7					Square 8				
	Day					Day					Day					Day				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Subject 21					Subject 26					Subject 31					Subject 36				
1	437	435	382	350	344	443	582	537	538	451	481	400	389	391	371	711	461	411	426	404
2	407	404	362	321	320	466	600	522	523	427	407	372	353	378	357	663	460	404	414	405
3	376	416	334	299	301	473	561	461	488	412	366	349	348	351	360	600	442	394	392	390
4	365	365	325	299	294	478	536	429	493	389	354	343	348	358	342	505	442	399	398	402
	Subject 22					Subject 27					Subject 32					Subject 37				
1	423	414	351	301	293	543	377	368	335	313	717	680	611	574	582	519	393	372	366	335
2	378	402	329	304	263	488	310	344	295	318	684	616	599	561	596	453	370	343	344	306
3	403	366	333	296	241	434	305	350	258	318	683	595	597	574	584	402	362	340	333	298
4	375	361	322	291	242	444	296	338	262	306	669	588	585	587	565	350	340	353	305	281
	Subject 23					Subject 28					Subject 33					Subject 38				
1	602	530	481	399	379	666	581	461	395	342	379	338	249	359	330	470	421	425	400	422
2	576	497	440	359	399	511	476	385	353	289	370	332	261	322	310	518	417	402	386	393
3	492	474	407	356	382	399	426	373	317	344	395	319	321	300	299	474	438	393	373	375
4	435	456	395	344	379	377	427	373	317	373	391	301	353	352	276	456	418	408	376	362
	Subject 24					Subject 29					Subject 34					Subject 39				
1	554	493	443	444	414	450	389	335	333	344	411	310	317	354	315	545	431	329	320	360
2	520	428	387	420	371	411	364	336	304	308	335	328	332	319	293	509	372	333	300	324
3	571	386	477	395	431	402	333	319	313	262	357	302	285	298	305	439	355	308	307	294
4	553	387	476	384	529	373	348	313	312	302	327	305	272	314	297	413	348	300	311	282
	Subject 25					Subject 30					Subject 35					Subject 40				
1	429	371	311	307	405	435	488	477	451	448	474	369	339	378	316	427	362	340	343	321
2	412	343	367	372	376	473	481	481	457	426	379	321	276	371	340	331	322	325	332	312
3	389	325	332	339	375	486	473	480	450	430	326	289	318	372	288	345	330	300	376	307
4	364	525	365	319	408	477	471	494	452	442	351	303	372	281	311	343	325	311	309	267

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* For method of scoring see p. 29.

TABLE C5

*Steering-wheel movement scores**

Period	Square 1					Square 2					Square 3					Square 4				
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5
	Subject 1					Subject 6					Subject 11					Subject 16				
1	691	648	580	637	574	883	551	588	550	485	897	909	532	643	612	652	627	599	547	551
2	611	645	582	601	602	749	578	491	513	491	792	777	521	605	583	582	633	551	536	544
3	598	581	555	619	551	679	599	471	500	461	709	806	505	619	559	537	558	517	532	524
4	556	577	573	620	556	733	555	500	525	447	695	730	493	579	569	546	597	539	544	517
	Subject 2					Subject 7					Subject 12					Subject 17				
1	845	648	607	609	667	912	791	533	678	570	946	770	701	666	800	703	555	470	483	553
2	863	637	689	609	607	865	733	584	630	602	879	824	605	678	608	695	514	415	475	534
3	750	631	655	593	613	854	660	531	702	558	669	730	628	584	584	620	493	426	425	509
4	726	602	574	601	630	775	631	499	654	635	697	708	588	543	614	613	468	409	421	533
	Subject 3					Subject 8					Subject 13					Subject 18				
1	971	760	871	1,716	1,138	872	833	656	678	728	676	514	563	532	598	614	602	653	661	709
2	836	716	798	1,123	1,046	724	801	662	707	615	632	428	577	534	624	587	539	621	674	666
3	894	672	779	997	976	712	743	646	577	635	683	441	565	572	573	550	558	591	517	638
4	811	673	753	941	1,054	783	833	632	576	737	663	440	590	610	541	528	530	614	524	563
	Subject 4					Subject 9					Subject 14					Subject 19				
1	662	548	507	601	713	779	636	553	497	596	791	633	618	618	539	791	898	694	679	1,051
2	609	573	490	599	625	712	647	571	580	579	740	628	557	620	518	792	691	521	559	900
3	602	583	514	610	664	700	690	511	508	643	793	572	529	571	510	647	646	451	536	943
4	624	561	554	627	656	605	654	572	623	608	813	574	557	600	512	672	548	499	521	858
	Subject 5					Subject 10					Subject 15					Subject 20				
1	847	682	718	835	747	917	722	602	476	477	986	644	896	792	619	988	676	1,040	849	798
3	756	663	623	714	719	918	633	604	446	482	901	664	779	804	602	809	634	1,079	856	764
3	701	616	664	556	774	710	612	618	523	485	883	648	735	808	624	768	583	916	818	737
4	637	552	664	704	700	746	642	527	515	501	858	686	805	806	575	782	603	831	740	728

(continued on p. 99)

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* For method of scoring see p. 29.

TABLE C5—(*continued*)

*Steering-wheel movement scores**

Period	Square 5					Square 6					Square 7					Square 8				
			Day					Day					Day					Day		
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
			Subject 21					Subject 26					Subject 31					Subject 36		
1	917	850	826	862	793	725	682	766	678	684	660	606	541	524	521	1,029	923	836	803	788
2	814	781	805	685	806	624	672	669	615	582	633	582	529	486	500	1,013	893	748	774	840
3	756	822	801	756	717	614	719	707	628	606	585	526	517	478	485	949	823	819	755	764
4	737	899	795	749	721	641	769	672	666	585	548	542	525	494	487	901	805	770	746	776
			Subject 22					Subject 27					Subject 32					Subject 37		
1	751	680	610	551	537	1,327	943	780	746	701	999	933	872	855	955	1,220	913	820	763	853
2	646	604	538	485	490	1,174	919	708	744	630	1,018	850	845	824	845	985	770	768	736	902
3	639	536	504	475	486	1,034	816	657	752	636	1,104	931	845	886	830	1,014	821	673	788	725
4	626	549	482	487	458	949	838	667	633	609	1,000	909	884	870	768	908	853	685	824	748
			Subject 23					Subject 28					Subject 33					Subject 38		
1	728	599	601	581	591	848	810	835	753	729	982	887	957	777	783	1,000	998	936	804	761
2	716	594	583	574	553	731	693	709	822	823	886	844	789	915	766	1,000	811	830	780	768
3	636	586	587	589	547	780	747	703	894	826	816	936	717	740	745	1,000	797	788	763	743
4	617	604	592	625	583	726	740	679	800	700	805	784	931	689	744	995	776	767	722	696
			Subject 24					Subject 29					Subject 34					Subject 39		
1	877	884	855	725	852	793	693	703	649	720	888	1,015	812	657	838	907	746	782	830	837
2	776	848	851	773	779	630	614	610	636	686	795	634	939	656	695	700	654	666	1,010	853
3	703	757	823	752	775	589	592	584	591	835	796	606	773	635	709	675	682	665	714	760
4	816	710	795	708	678	590	576	620	606	645	879	646	757	709	699	663	666	596	639	821
			Subject 25					Subject 30					Subject 35					Subject 40		
1	977	759	931	838	693	698	695	677	661	657	1,193	1,199	1,120	858	846	687	699	699	665	707
2	827	737	948	753	667	574	627	645	628	614	1,086	1,217	1,182	1,053	886	607	690	636	687	625
3	770	734	861	695	666	557	575	671	655	592	1,041	988	1,085	885	880	617	650	665	652	621
4	816	727	793	768	680	572	543	634	648	578	1,000	910	1,004	927	811	605	621	625	630	601

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* For method of scoring see p. 29.

TABLE C6

*'Effective' steering-wheel reversal scores**

Period	Square 1					Square 2					Square 3					Square 4				
			Day					Day					Day					Day		
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
			Subject 1					Subject 6					Subject 11					Subject 16		
1	104	120	99	110	101	119	104	91	92	100	152	141	113	113	120	117	108	107	97	102
2	100	114	99	109	103	119	98	81	79	89	136	125	110	107	117	118	107	97	91	102
3	94	107	86	117	93	108	103	77	76	81	115	115	99	111	108	109	92	91	91	88
4	85	104	94	112	100	107	94	86	84	76	110	113	96	98	103	111	116	99	92	89
			Subject 2					Subject 7					Subject 12					Subject 17		
1	147	117	95	98	109	130	122	84	109	91	151	117	115	106	127	105	90	73	91	103
2	151	115	113	99	100	115	103	75	98	90	113	111	103	114	102	96	85	67	80	94
3	132	116	110	104	99	112	86	76	106	88	102	106	106	99	99	90	70	68	70	81
4	128	102	97	97	99	111	83	72	98	95	96	128	101	92	103	96	67	63	69	85
			Subject 3					Subject 8					Subject 13					Subject 18		
1	168	125	159	212	189	124	118	111	119	121	106	91	99	104	105	95	95	97	107	110
2	137	120	145	171	155	102	124	99	126	105	101	98	94	105	101	92	88	94	99	103
3	152	121	138	139	139	104	108	114	103	111	117	89	97	99	93	86	87	91	85	98
4	140	113	131	131	143	104	123	106	102	117	107	86	94	107	93	81	85	95	91	85
			Subject 4					Subject 9					Subject 14					Subject 19		
1	107	118	89	91	108	159	176	120	97	113	144	108	109	105	104	149	158	137	141	158
2	106	106	78	85	95	146	147	98	104	110	143	111	96	119	87	147	155	120	110	135
3	104	100	87	87	93	116	140	91	79	108	143	115	99	106	96	134	128	83	93	152
4	107	92	97	101	101	102	133	96	111	112	143	110	109	115	97	129	107	84	87	149
			Subject 5					Subject 10					Subject 15					Subject 20		
1	120	98	107	106	104	146	119	105	72	96	143	109	131	125	97	173	125	190	160	131
2	98	93	103	92	100	134	100	95	69	85	141	106	128	130	94	137	118	195	163	134
3	104	100	108	85	101	115	94	89	82	79	131	104	111	134	94	127	116	173	152	128
4	92	84	108	76	92	108	102	76	73	79	120	112	122	123	89	134	109	142	146	125

(continued on p. 101)

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* For method of scoring see p. 29.

TABLE C6—(*continued*)

*'Effective' steering-wheel reversal scores**

Period	Square 5					Square 6					Square 7					Square 8				
	Day 1	2	3	4	5	Day 1	2	3	4	5	Day 1	2	3	4	5	Day 1	2	3	4	5
	Subject 21					Subject 26					Subject 31					Subject 36				
1	183	160	166	168	153	135	106	143	132	133	109	84	74	71	68	155	139	130	124	118
2	150	135	150	122	152	114	115	125	119	110	100	84	78	65	66	145	135	120	128	129
3	139	139	141	143	137	116	125	131	116	119	98	71	75	66	72	136	129	137	119	120
4	143	159	148	148	144	109	128	117	130	113	85	70	69	65	68	127	130	115	127	117
	Subject 22					Subject 27					Subject 32					Subject 37				
1	106	101	96	77	75	237	149	140	150	128	173	170	138	146	180	178	135	123	112	125
2	99	101	85	68	73	245	141	130	137	116	178	145	164	159	171	150	127	120	109	134
3	103	88	82	65	68	190	136	120	129	116	177	171	163	156	164	158	124	103	117	105
4	92	85	70	73	63	189	136	119	112	118	181	173	162	171	181	134	131	107	125	119
	Subject 23					Subject 28					Subject 33					Subject 38				
1	134	101	108	99	102	137	136	147	141	127	127	124	128	115	121	142	154	156	128	121
2	137	106	107	100	94	112	117	118	141	146	116	123	113	128	119	136	137	135	125	119
3	123	107	104	94	89	123	122	114	149	142	119	136	112	109	110	141	124	130	119	113
4	119	115	103	96	97	111	123	113	132	135	118	118	114	97	109	139	133	130	110	101
	Subject 24					Subject 29					Subject 34					Subject 39				
1	138	140	130	118	139	164	125	119	112	107	161	147	142	109	134	145	134	136	141	136
2	121	130	118	125	119	116	112	105	108	111	127	107	175	111	126	127	101	129	146	139
3	109	110	127	121	114	112	112	98	105	125	140	103	125	106	124	123	111	115	114	125
4	132	107	127	110	115	108	106	97	104	104	142	103	119	122	119	132	105	101	104	146
	Subject 25					Subject 30					Subject 35					Subject 40				
1	174	137	154	155	138	128	140	128	117	115	178	164	166	150	138	117	122	111	107	98
2	154	132	150	144	137	109	121	116	113	110	165	173	155	164	159	103	108	106	100	95
3	138	130	140	136	137	107	121	130	112	115	157	133	154	146	159	100	107	108	105	100
4	149	127	151	162	123	105	101	125	112	106	160	135	140	133	146	100	104	101	94	94

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* For method of scoring see p. 29.

TABLE C7

*'Ineffective' steering-wheel reversal scores**

Period	Square 1					Square 2					Square 3					Square 4				
	Day					Day					Day					Day				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Subject 1					Subject 6					Subject 11					Subject 16				
1	52	41	44	56	50	74	48	71	35	28	42	30	46	40	43	63	24	36	36	24
2	43	31	34	42	36	57	48	51	45	48	39	31	44	33	50	50	29	33	35	25
3	42	29	38	56	39	41	48	46	35	48	47	26	32	30	51	47	38	33	35	29
4	37	33	51	52	42	44	46	51	26	48	41	29	46	37	53	41	26	34	36	25
	Subject 2					Subject 7					Subject 12					Subject 17				
1	35	35	31	32	24	46	39	49	24	47	61	40	33	41	40	41	47	51	53	43
2	34	24	31	23	20	39	29	36	30	39	49	45	44	26	40	42	31	33	37	33
3	43	22	40	26	25	33	29	33	23	37	46	55	43	36	35	37	32	34	32	37
4	34	28	32	27	26	31	32	37	29	36	36	40	45	53	35	29	41	36	37	35
	Subject 3					Subject 8					Subject 13					Subject 18				
1	62	63	75	104	82	77	75	46	40	49	89	82	43	67	64	38	28	41	35	36
2	57	36	52	95	69	50	78	39	44	68	58	56	45	62	43	29	26	37	34	23
3	51	34	53	80	76	54	60	33	43	56	63	41	38	47	47	25	28	26	38	30
4	50	50	54	69	69	48	48	51	50	50	69	39	42	41	45	30	27	31	31	24
	Subject 4					Subject 9					Subject 14					Subject 19				
1	28	19	19	36	40	65	62	51	39	39	110	68	55	47	42	133	142	109	79	79
2	29	26	17	45	37	54	40	33	29	27	93	60	46	75	46	135	114	83	85	110
3	30	20	24	50	32	50	32	38	41	27	113	63	48	64	51	124	101	79	77	87
4	37	22	24	41	39	43	32	29	23	32	135	65	47	64	61	171	92	104	78	80
	Subject 5					Subject 10					Subject 15					Subject 20				
1	18	14	12	17	32	75	48	58	43	33	60	77	58	53	29	68	66	71	71	64
2	15	17	15	23	20	46	40	40	34	30	66	50	70	42	42	57	48	44	53	51
3	15	17	16	16	23	42	37	37	33	39	60	51	83	39	34	50	45	51	42	50
4	21	21	16	20	24	39	36	35	37	38	51	50	83	35	31	41	48	43	38	46

* For method of scoring see p. 29.

(continued on p. 103)

TABLE C7—(*continued*)

'*Ineffective*' *steering-wheel reversal scores**

Period	Square 5					Square 6					Square 7					Square 8				
	Day					Day					Day					Day				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
	Subject 21					Subject 26					Subject 31					Subject 36				
1	93	80	92	73	79	80	89	78	83	46	45	28	32	35	31	75	49	47	53	53
2	81	50	82	63	67	75	116	76	53	37	31	30	37	27	30	77	55	54	44	57
3	67	47	81	64	68	76	70	66	48	44	35	25	40	29	28	74	51	53	55	49
4	73	51	65	61	66	71	70	60	57	45	36	29	40	27	26	68	49	59	50	38
	Subject 22					Subject 27					Subject 32					Subject 37				
1	36	22	19	16	21	99	67	72	51	48	150	137	132	119	130	72	44	35	23	22
2	16	24	21	18	15	82	33	45	51	53	123	88	94	87	109	49	37	25	20	34
3	24	19	18	22	18	66	35	48	38	55	120	85	84	99	126	47	44	21	19	26
4	21	15	16	16	17	59	32	51	40	43	112	88	83	85	103	35	32	25	29	32
	Subject 23					Subject 28					Subject 33					Subject 38				
1	69	57	55	42	41	123	103	67	64	55	57	48	36	52	52	53	36	53	36	52
2	80	54	47	36	52	78	59	48	52	44	52	56	37	46	46	46	44	45	33	51
3	59	58	38	42	37	50	55	61	47	72	44	40	36	44	45	42	45	49	34	33
4	55	51	38	33	45	45	49	40	36	56	49	36	36	51	37	53	35	40	26	32
	Subject 24					Subject 29					Subject 34					Subject 39				
1	82	58	40	52	42	50	43	46	38	41	51	54	59	62	54	81	49	31	48	55
2	46	39	39	52	37	44	31	46	42	28	50	57	63	51	59	84	51	47	47	64
3	60	42	50	34	42	42	31	43	37	28	48	56	54	50	55	78	60	61	48	60
4	67	30	54	30	47	40	32	42	34	44	57	69	72	56	56	67	41	54	48	61
	Subject 25					Subject 30					Subject 35					Subject 40				
1	72	65	53	52	67	44	56	39	30	47	82	51	48	68	73	28	31	38	33	29
2	61	51	46	56	67	48	43	36	40	44	49	43	48	68	77	30	25	24	35	24
3	56	49	43	51	50	44	37	33	41	39	52	43	48	67	65	26	23	24	28	20
4	48	56	55	57	76	43	46	33	36	38	48	51	48	56	67	24	22	28	28	18

* For method of scoring see p. 29.

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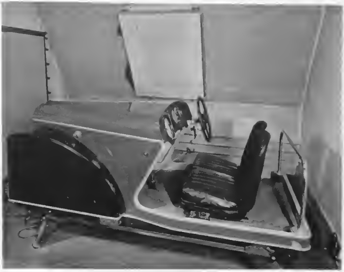

PLATE I

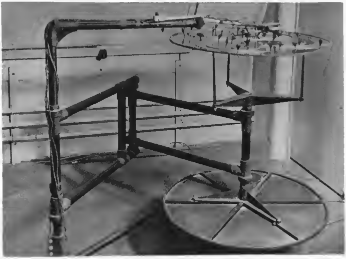

PLATE II

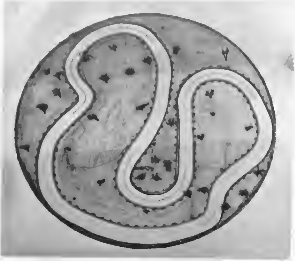

PLATE III

PLATE IV